U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-257 969

Evaluation of a Compartmentalized Refuse Collection Vehicle for Separate Newspaper Collection

SCS Engineers, Long Beach, Calif

Prepared for

Environmental Protection Agency, Washington, D C Office of Solid Waste Management Programs

May 76

BEST SELLERS

FROM NATIONAL TECHNICAL INFORMATION SERVICE

NTIS

Product Liability Insurance: Assessment of Related Problems and Issues. Staff Study
PB-252 204/PAT 181 p PC$9.50/MF$3.00

Evaluation of Home Solar Heating System
UCRL-51 711/PAT 154 p PC$6.75/MF$3.00

Developing Noise Exposure Contours for General Aviation Airports
ADA-023 429/PAT 205 p PC$7.75/MF$3.00

Cooling Tower Environment, 1974. Proceedings of a Symposium Held at the University of Maryland Adult Education Center on Mar. 4-6, 1974
CONF-74 0302/PAT 648 p PC$13.60/MF$3.00

Biological Services Program. Fiscal Year 1975
PB-251 738/PAT 52 p PC$4.50/MF$3.00

An Atlas of Radiation Histopathology
TID-26-676/PAT 234 p PC$7.60/MF$3.00

Federal Funding of Civilian Research and Development. Vol. 1. Summary
PB-251 266/PAT 61 p PC$4.50/MF$3.00

Federal Funding of Civilian Research and Development. Vol. 2. Case Studies
PB-251 683/PAT 336 p PC$10.00/MF$3.00

Handbook on Aerosols
TID-26-608/PAT 141 p PC$6.00/MF$3.00

for the Assessment of Ocean Outfalls
ADA-023 514/PAT 34 p PC$4.00/MF$3.00

Guidelines for Documentation of Computer Programs and Automated Data Systems
PB-250 867/PAT 54 p PC$4.50/MF$3.00

NOx Abatement for Stationary Sources in Japan
PB-250 586/PAT 116 p PC$5.50/MF$3.00

U.S. Coal Resources and Reserves
PB-252 752/PAT 16 p PC$3.50/MF$3.00

Structured Programming Series. Vol. XI. Estimating Software Project Resource Requirements
ADA-016 416/PAT 70 p PC$4.50/MF$3.00

Assessment of a Single Family Residence Solar Heating System in a Suburban Development Setting
PB-246 141/PAT 244 p PC$8.00/MF$3.00

Technical and Economic Study of an Underground Mining, Rubblization, and In Situ Retorting System for Deep Oil Shale Deposits. Phase I Report
PB-249 344/PAT 223 p PC$7.75/MF$3.00

A Preliminary Forecast of Energy Consumption Through 1985
PB-251 445/PAT 69 p PC$4.50/MF$3.00

HOW TO ORDER

When you indicate the method of payment, please note if a purchase order is not accompanied by payment, you will be billed an addition $5.00 *ship and bill* charge. And please include the card expiration date when using American Express.

Normal delivery time takes three to five weeks. It is vital that you order by number or your order will be manually filled, insuring a delay. You can opt for *airmail delivery* for a $2.00 charge per item. Just check the *Airmail Service* box. If you're really pressed for time, call the NTIS Rush Order Service. (703) 557-4700. For a $10.00 charge per item, your order will be airmailed within 48 hours. Or, you can pick up your order in the Washington Information Center & Bookstore or at our Springfield Operations Center within 24 hours for a $6.00 per item charge.

You may also place your order by telephone or TELEX. The order desk number is (703) 557-4650 and the TELEX number is 89-9405.

Whenever a foreign sales price is NOT specified in the listings, all foreign buyers must add the following charges to each order: $2.50 for each paper copy; $1.50 for each microfiche; and $10.00 for each Published Search.

Thank you for your interest in NTIS. We appreciate your order.

METHOD OF PAYMENT

☐ Charge my NTIS deposit account no._____

☐ Purchase order no._____

☐ Check enclosed for $_____

☐ Charge to my American Express Card account number

Card expiration date_____

Signature_____

☐ Airmail Services requested

NAME_____

ADDRESS_____

CITY, STATE, ZIP_____

Item Number	Quantity		Unit Price*	Total Price*
	Paper Copy (PC)	Microfiche (MF)		
			Sub Total	
			Additional Charge	
			Enter Grand Total	

All Prices Subject to Change

11/76

Clip and mail to:

NTIS

National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Va. 22161
(703) 557-4650 TELEX 89-9405

PB 257 969

EVALUATION OF A COMPARTMENTALIZED REFUSE COLLECTION VEHICLE FOR SEPARATE NEWSPAPER COLLECTION

This final report (SW-126c) describes work performed for the Federal solid waste management programs under contract no. 68-01-3191 and is reproduced as received from the contractor.

U.S. ENVIRONMENTAL PROTECTION AGENCY

1976

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Evaluation of a Compartmentalized Refuse Collection Vehicle for Separate Newspaper Collection			5. Report Date May, 1976 6.
7. Author(s) SCS Engineers			8. Performing Organization Rept. No.
9. Performing Organization Name and Address SCS Engineers 4014 Long Beach Boulevard Long Beach, California 90807			10. Project/Task/Work Unit No. 11. Contract/Grant No. 68-01-3191
12. Sponsoring Organization Name and Address Resource Recovery Division Office of Solid Waste Management Programs U.S. Environmental Protection Agency Washington, D.C. 20460			13. Type of Report & Period Covered Final Report 14.

15. Supplementary Notes

COLOR ILLUSTRATIONS REPRODUCED IN BLACK AND WHITE

16. Abstracts

The purpose of the report is to present information on the economic viability of a compartmentalized refuse collection vehicle for separate newspaper collection. The compartmentalized vehicle is compared to the rack and separate truck approaches. A model is developed for analyzing alternative collection approaches to minimize and/or compare applicable costs. The three methods are analyzed for their cost-effectiveness when newspaper revenue is $8/ton and $25/ton. The report concludes that the compartmentalized vehicle is economically viable. Furthermore, it states that the economics of the compartmentalized vehicle are more favorable than the rack and separate truck approaches. The separate truck approach, however, is more economical with more than 50% participation and a monthly collection frequency.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

Source Separation
Separate Collection
Recycling Systems
Materials Recovery

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
	20. Security Class (This Page) UNCLASSIFIED	

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement or recommendation for use by the U.S. Government.

TABLE OF CONTENTS

Section		Page
I.	SUMMARY AND CONCLUSIONS	1
	Operating Characteristics	1
	Economic Viability	1
II.	INTRODUCTION	3
III.	BACKGROUND AND APPROACH	7
	Background	7
	Approach	8
IV.	CONCEPT EVALUATION	11
	Pilot Area Characteristics	11
	Startup Costs	16
	Performance Parameters	18
	Program Economics	29
V.	ACKNOWLEDGEMENTS	41
VI.	APPENDICES	43
	A. Rancho Palos Verdes, California	A-1
	B. Fullerton, California	B-1
	C. Newport Beach, California	C-1
	D. Systems Analysis Data Development	D-1
	E. Collection Model	E-1

FIGURES

Number		Page
1	Compartmentalized Shu-Pak with Hydraulic Newspaper Loading Device	4
2	Discharging Separately Collected Newspapers (Conceptual)	5
3	Residential Refuse Collected in Rancho Palos Verdes	12
4	Transfer Ramp used for Separate Newspaper Collection, Newport Beach	19
5	Compartmentalized Truck Operational Sequence for Collection and Disposal	20
6	Impact of Separate Newspaper Collection on Refuse Collection; First Collection Day of Week (Compartmentalized Truck)	24
7	Impact of Separate Newspaper Collection on Refuse Collection; Second Collection Day of Week (Compartmentalized Truck)	25
8	Impact of Compartmentalization on Legal Payload	27
9	Rack Approach to Separate Newspaper Collection	30
10	Separate Truck Approach to Separate Newspaper Collection	30
11	Effective Cost for Compartmentalized Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis	32
12	Effective Cost for Compartmentalized Collection of Separated Newspaper Pending Recommended Equipment Modifications	33

FIGURES (Continued)

Number		Page
13	Effective Cost for Rack Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis	36
14	Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/wk Separate Collection	37
15	Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/2 wk Separate Collection	38
16	Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/mo Separate Collection	39

TABLES

Number		Page
1	Residential Refuse Characteristics	14
2	Selected Socio-Economic Characteristics	17

I

SUMMARY AND CONCLUSIONS

A compartmentalized Shu-Pak can optimize both mixed refuse and separate newspaper collection operations. The appealing aspects of the compartmentalized Shu-Pak include:

- Compartment capacity and rate of paper loading can be tailored to local conditions and requirements.
- Minimal driver orientation time is required to attain operating proficiency.
- Mixed refuse and separated newspaper can be loaded in the same hopper area without losing the flexibility to load refuse from both sides of the truck.
- Installation of the compartment does not reduce payload capacity. Conversely, the compartmentalized approach can enhance weight distribution.

Separately collected newspaper was not contaminated when dumped through the truck body.

Separate newspaper collection with the compartmentalized test unit required incremental time for newspaper loading and transfer. Proper system design, however, can reduce incremental loading time to about 3 seconds per participating stop. Previous studies indicate that this incremental time can be readily absorbed without necessitating additional labor and equipment.

Minimization of newspaper handling time necessitates that transfer be performed at the disposal site or a location on the haul route.

Economic Viability

The compartmentalized approach to separate collection of newspaper is economically viable.

- Startup costs are required for implementation of the compartmentalized approach. Installation of the compartment and loading mechanism

on the collection vehicle were estimated to be $1,700 per unit. A ramp must be available to facilitate transfer of separately collected newspaper (estimated cost: $10,000).

- The economics of the compartmentalized Shu-Pak are more favorable than a rack-equipped Shu-Pak. Incremental newspaper loading of the two approaches are similar. Newspaper transfer time, however, is less with the compartmentalized unit.

- The economics of the compartmentalized Shu-Pak are more favorable than the separate truck approach when collection frequency is either once per week or bi-weekly. At greater than 50 percent participation and a monthly collection frequency, the separate truck approach becomes more economical.

The compartmentalized approach appears adaptable to other recyclable components of mixed municipal refuse, i.e., glass and metal.

II

INTRODUCTION

As currently practiced, curbside separate collection of recyclable materials is accomplished via one of two approaches:

- A separate truck (or trucks) designated for collection of separated materials. Generally, the viability of the separate truck approach increases with participation. At low participation rates, capacity of the separate truck may not be fully utilized; however, as participation increases, capacity is better utilized.

- A rack (or racks) to isolate separated material from mixed refuse during collection. The most appealing aspect of the rack approach is that mixed refuse and separated material can be collected simultaneously by the same crew. Also, householder refuse set-out habits need not be altered.

In a recent study*, both approaches were shown to have merit as a means of reducing disposable waste quantities while lowering overall solid waste management costs. The results further indicated that a compartmentalized collection vehicle could prove more beneficial than either approach by incorporating the best features of each. A compartment properly sized to hold separated material at a given participation rate, could optimize both mixed and separate collection operations.

Maxon Industries of Los Angeles, California, developed a prototype compartmented vehicle. As characterized in Figures 1 and 2, a 3 cu yd compartment and loading "bucket" were designed for installation on a standard side loading Shu-Pak.** The crew member loads separated newspaper and mixed refuse in the same location, the newspaper being hydraulically loaded into the compartment after placement in the "bucket."

---

* SCS Engineers, Analysis of Source Separate Collection of Recyclable Solid Waste; Separate Collection Studies. [v.1]. Environmental Protection Publication SW-95c.1. U.S. Environmental Protection Agency, 1974 [157 p.]. (Distributed by National Technical Information Service, Springfield, Va., as PB 239 775.)

** By weight, newspaper amounts to about 10 percent of the residential refuse collected in Rancho Palos Verdes. The 3 cu yd compartment consumes approximately 10 percent of the 29 cu yd body.

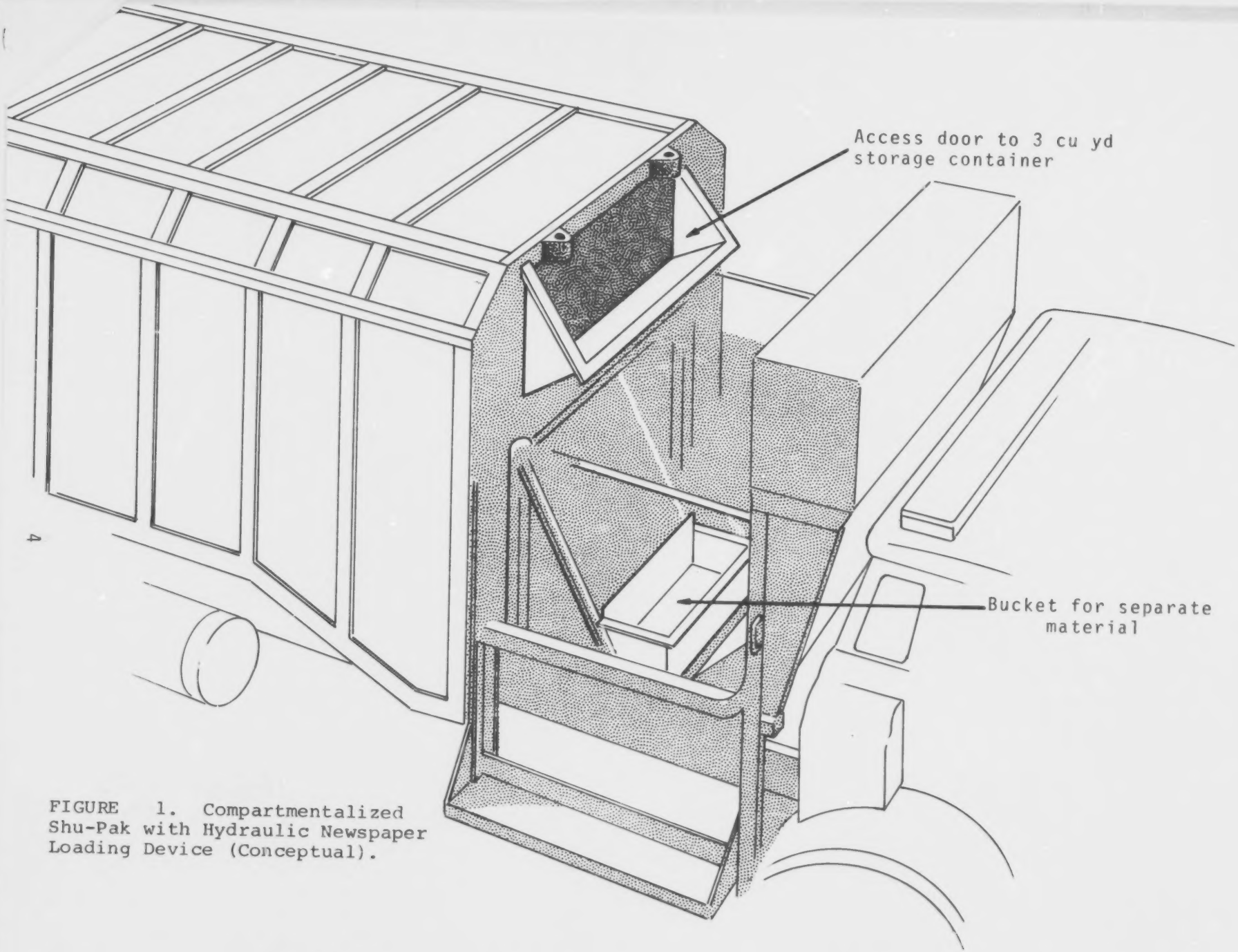

FIGURE 1. Compartmentalized Shu-Pak with Hydraulic Newspaper Loading Device (Conceptual).

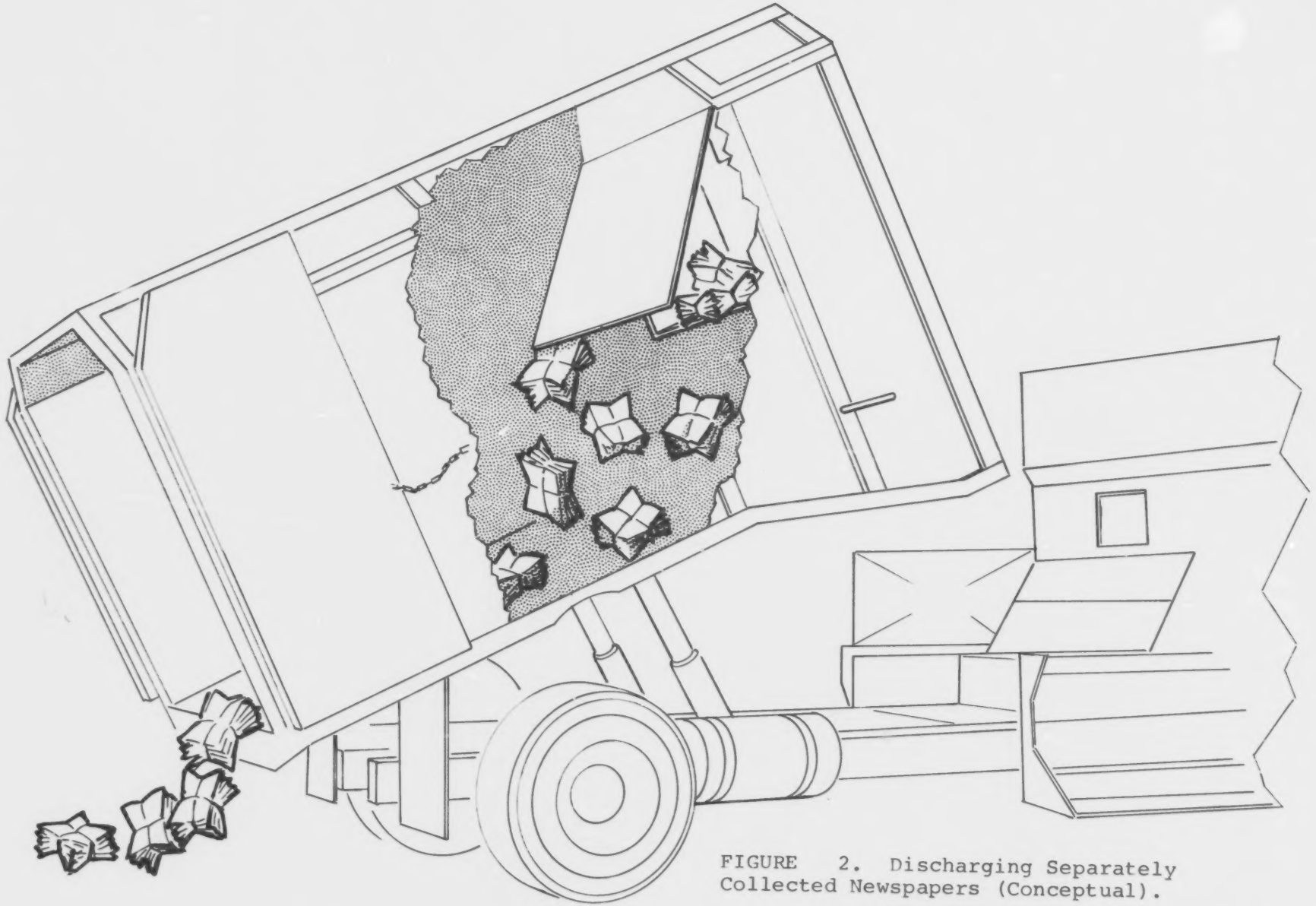

FIGURE 2. Discharging Separately Collected Newspapers (Conceptual).

A private contractor, Browning Ferris Industries, Inc. (BFI), permitted Maxon to install the equipment for test and evaluation on an existing BFI truck for use in the city of Rancho Palos Verdes, California. City officials agreed to a test program, and the Palos Verdes chapter of the American Association of University Women provided in-kind public relations support for curbside separate newspaper collection in a pilot area encompassing about 1,100 homes.

The Los Angeles County Sanitation Districts built a transfer ramp at the Palos Verdes Landfill to facilitate unloading of newspapers separately collected during the pilot program.

Evaluation of the compartmentalized approach to separate collection was conducted by SCS Engineers under contract to the U.S. Environmental Protection Agency.

The study objective was to evaluate and report on the operating characteristics, performance, cost, and overall efficiency of the compartmentalized Shu-Pak when utilized for separate newspaper collection. Comparisons were also to be made with the separate truck and rack approaches to separate collection.

III

BACKGROUND AND APPROACH

Background

The Palos Verdes Peninsula is located about 25 miles south of Los Angeles. The area is one of the more affluent and well-educated residential areas in southern California. Following Earth Day 1970, the Palos Verdes Chapter of the American Association of University Women, with cooperation of the Los Angeles County Sanitation Districts opened a recycling center to accept source separated materials from 61,000 peninsula residents.* The recycling center has operated continually since inception, and receives about 100 tons of material per month. Creation of the recycling center was viewed as the first step toward a more systematic approach to recovery of recyclable residential solid waste. The second step was initiation of a curbside separate collection program.

Solid waste collection on the peninsula is conducted by five private contractors. One contractor, BFI, collects residential waste from about 7,700 persons residing in 2,200 homes within the city of Rancho Palos Verdes. Curbside collection service is provided twice weekly using side-loading compaction vehicles.

Installation of the compartment and "bucket" on one BFI truck was performed by Maxon in November, 1974. The separate collection program commenced the first week of December, 1974.

The program immediately experienced difficulties. Knowledge of the pending program from an effective door-to-door public relations effort resulted in pilot area residents accumulating newspapers for several weeks. As the compartment was sized to meet the Los Angeles area norm of newspaper (about 10 percent of residential solid

---

* Four cities are located on the peninsula: Rancho Palos Verdes, Palos Verdes Estates, Rolling Hills, and Rolling Hills Estates.

waste), separated newspaper quantities far exceeded compartment capacity. When the compartment filled, additional newspaper could not be accommodated, and were treated as mixed waste. This created resident disillusionment with the program, and undoubtedly curtailed some degree of participation.

During the initial days of the program, it was also observed that the dead-man control used to raise and lower the bucket resulted in excessive time to handle separated newspaper. To correct the situation required removing the truck from the route for two days. Removal of the compartmentalized truck again resulted in disposal of bundled newspaper and created further disillusionment on the part of pilot area residents.

The driver also experienced problems with the newspaper transfer operation prior to construction of the transfer ramp by the Los Angeles County Sanitation Districts. During the interim period of about three months, the driver unloaded refuse at the landfill and proceeded to the nearby Palos Verdes Recycling Center where separately collected newspapers were dumped on the ground and manually loaded into a roll-off bin. This added from one-half to one hour per day to the driver's time. Further compounding the problem was a refuse collection strike during which all material placed curbside was treated as refuse. The cumulative effect of driver and resident disillusionment created some problems with concept credibility. However, they did not affect the evaluation due to the methodology used.

Approach

Two criteria were used to evaluate the compartmentalized concept:

1. Impact on normal collection operations
2. Economic viability

Impact on Collection

Prior to modifying the truck, a two-week time study was performed to serve as the basis for assessing the impact, if any, of compartmentalization on collection operations. The second BFI truck operated in Rancho Palos Verdes (designated as the "control truck") was also monitored during the same time period.

An additional two weeks of time studies were conducted to assess concept impact after the following had occurred:

1. Sufficient time passed for the newspaper set-out rate to achieve normalcy.

2. Elimination of the dead-man control in favor of an air control valve.

3. Operator familiarity with the equipment.

The control truck was also monitored during the same time period.

The driver cooperated with the study team such that the results attained and reported herein are believed valid. Thus, the unfortunate decline in participation due to resident disillusionment only affects conclusions on adequacy of compartment size and problems that would be encountered when generation exceeds capacity.

Economic Viability

The effectiveness of the compartmentalized approach to separate collection is related to the ability of the mixed collection system to absorb incremental time requirements for newspaper collection and transfer. Any incremental costs must be offset by revenue and diverted disposal savings to achieve economic viability. Using residential participation rate as a proxy for the rate of newspaper recovery, a simulation model was used to assess the compartmentalized approach assuming that the incremental time requirements could not be absorbed into the normal work day.

The results of the evaluation were then compared to separate collection using rack and separate truck approaches. The data input for collection time parameters for the rack and separate truck were derived from time studies conducted in the southern California cities of Fullerton and Newport Beach which also use the Shu-Pak.

IV

CONCEPT EVALUATION

Results of the evaluation are summarized in this section in terms of performance parameters and economic viability. Prior to presenting the results, characteristics related to separate collection in the Rancho Palos Verdes pilot area and start-up costs associated with the compartmentalized approach are briefly discussed.

Pilot Area Characteristics

Refuse Characteristics

Refuse Generation. Weekly weight receipts for both collection trucks were obtained for a one-year period (Figure 3). Although varying from week-to-week, the average quantity of refuse collected by the compartmentalized and control trucks were almost identical:

Truck	Average Refuse Quantity Collected (tons per week)	Per Capita Generation Rate (lbs per person per day)
Compartmentalized	50.4	3.74
Control	50.2	3.72

Figure 3 also indicates the time periods during which the time studies were conducted. The compartmentalized truck was monitored during periods when waste generation exceeded the mean. Refuse quantities collected by the control truck were less than the mean before the test program, but similar to the compartmented unit after the test program commenced. Thus, the compartmentalized truck was monitored during periods demanding of equipment and labor.

Due to the similarity of quantities collected by the compartmentalized truck during "before and after" periods, the average refuse generation rate for these weeks was used during the evaluation:

Preceding page blank

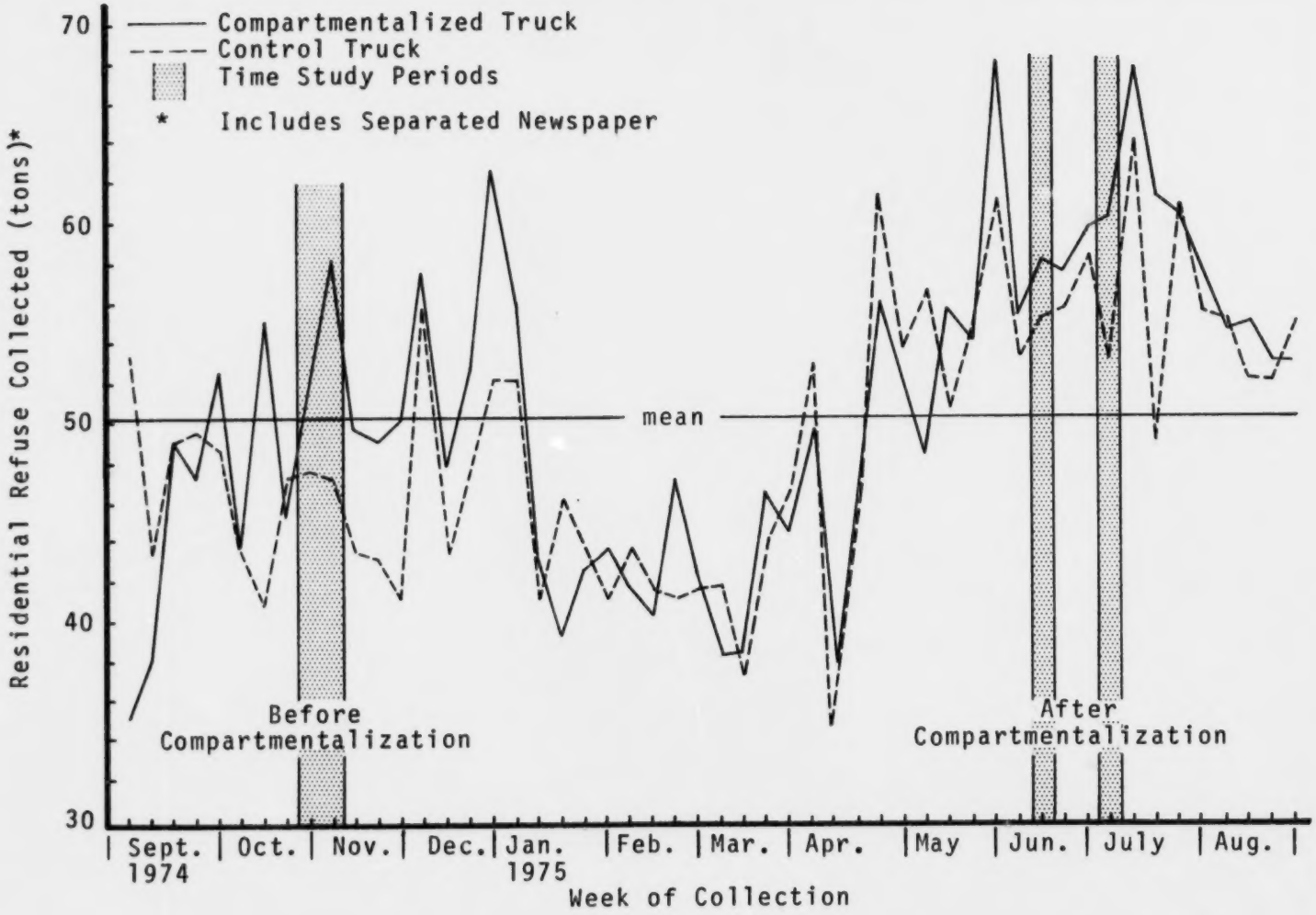

FIGURE 3. Residential Refuse Collected in Rancho Palos Verdes

Collection Day	Refuse Generation Rates (tons/wk)	(lbs/hshld/wk)	(lbs/person/day)
First of week	33.6	61	4.36
Second of week	23.6	43	4.10
Total/Average	57.2	104	4.24

Refuse Items. The term "refuse item" is used throughout the analysis to designate items placed curbside for collection:

Refuse Item	Description
Container	Fiber, metal, or plastic container
Bags	Paper or plastic bag
Other	Bundled brush, lawn chairs, or any other discarded item not amenable to containerization

The efficiency of manual refuse collection is influenced by the type of refuse item placed curbside for collection. Containers must be returned to the curb after being emptied into the loading hopper. Bags and "other" items are generally pitched into the loading hopper with inherent time savings. Thus, the type of item, or mix thereof, can be important when evaluating an alternative approach to refuse collection.

Table 1 presents the refuse item characteristics observed during the field studies before and after commencement of the separate collection program.* As seen, the average number of items per stop increased after commencement of the separate collection program (newspaper bundles not included in the item count). The increase in average number of items per stop was accompanied by a decrease in loading time per stop.+ The initial hypothesis that the item mix

* Frequency distribution graphs presented in Appendix A.
+ Load time analysis presented in Appendix A.

TABLE 1

RESIDENTIAL REFUSE CHARACTERISTICS

Refuse Item	Collection Day of Week: First* Before++	First* After	Second+ Before++	Second+ After
Compartmentalized Truck				
Containers	2.6	2.7	1.9	2.1
Bags	0.3	0.4	0.2	0.3
Other	0.6	0.8#	0.4	0.7#
Total	3.5	3.9	2.5	3.1
Ave.weight/stop(lbs)	60	62	43	39
Control Truck				
Containers	2.3	2.4	2.0	**
Bags	0.3	0.4	0.2	**
Other	0.9	0.8	0.5	**
Total	3.5	3.6	2.7	**
Ave.weight/stop(lbs)	49	60	35	38

* Monday, Tuesday, or Wednesday
\+ Thursday, Friday, or Saturday
\# Does not include newspaper bundles
** No data
++ Before separate newspaper collection program

changed from non-disposable containers (metal/plastic containers) to disposables (paper and plastic bags, bundled brush) was invalidated by the breakdown in Table 1 which shows an increase in each item. Therefore, the conclusion reached was that the task system* induces greater loading speed during heavy generation periods and more than compensates for the occurrence of more items per stop.

Newspaper Characteristics

Bundling Requirements. Separated newspaper was required to be bundled for collection. Acceptable bundling techniques were by tying string or twine around newspapers, or placing newspapers in grocery bags. The vast majority of pilot area residents opted to use grocery bags. In that bundles are manually handled only once during the collection process, bags ripping open or newspapers slipping out were not prevalent problems. Although not observed or quantified during the field studies, the driver indicated that grocery bags tended to split when wet (rain).

Newspaper Generation. A weekly newspaper generation rate of 13.0 lbs per household per week in the pilot area was based on the quantities collected during field studies conducted after the program had attained normalcy in weekly set-out patterns. The number of newspaper bundles set out by participating households ranged from one to five with an average of 1.5, or an average weight of 8.7 lbs per bundle.

Participation

An effective public relations program coupled with high socio-economic status in an area receiving separate collection service should be indicative of a successful program. The pilot area in Rancho Palos Verdes met both criteria:

- A public relations program consisting of newspaper articles, a series of flyers, and a door-to-door information campaign was conducted in the pilot area by the Palos Verdes chapter of the American Association of University Women.

---

*The task system operates on the basis that a collection crew is assigned an area from which to collect refuse. When all refuse from the area has been collected, the crew is finished regardless of time of day. Crew members are paid for a full day's work even if an undertime situation results.

. The pilot area consisted of about 7,700 people residing in 2,200 single family household, Table 2 presents selected socio-economic data for the pilot area, the city of Rancho Palos Verdes, and the Los Angeles/Long Beach SMSA*. As shown, the pilot area is characterized by a high-income, highly educated populous with family size about that of the national average (3.5 persons/household).

During the two week period in which time studies of the compartmentalized concept was monitored, a participation rate+ ranging from 30 to 40 percent was observed. Although adequate to assess most concept parameters, a greater participation rate would have been desirable to test the adequacy of compartment size and associated newspaper behavior patterns (angle of repose, density, etc.) during route conditions.

One noteworthy observation made during the field studies was that householders were equally inclined to set out bundles on either, but not both collection days.# This statement is substantiated by comparison of the average daily participants on the first and second collection day of the week:

Program Participants
(number per route per day)

Monday/ Thursday	Tuesday/ Friday	Wednesday/ Saturday
73/71	58/56	72/72

Startup Costs

The initial cost to compartmentalize the Shu-Pak used in the Rancho Palos Verdes test was about $1,400 which included installation of the compartment; cutting an opening in the

---

* Standard Metropolitan Statistical Area.

\+ Participation rate is defined as the number of households, expressed as a percent of total households in separate collection service area, placing newspaper bundles out for separate collection.

\# Similarly, there was no notable difference in the number of newspaper bundles between the first and second collection day.

TABLE 2

SELECTED SOCIO-ECONOMIC CHARACTERISTICS*

Socio-Economic Characteristics	Area		
	Rancho Palos Verdes		Los Angeles/Long Beach SMSA
	Pilot Area+	Entire City	
Population	7,700	38,910	7,032,080
Persons/household	3.5	3.8	2.8
Education/median year completed	15.4	13.3	12.4
Median family income	$22,000	$21,080	$10,970

* U. S. Bureau of the Census. Census of population and housing: 1970. Census tracts; final report PHC(1)-117, Los Angeles-Long Beach, Calif., SMSA, pts.

+ Residential area serviced by BFI.

bulkhead through which the newspaper is loaded; mounting the lift-arms, bucket, and support members; and installation of the controls. Subsequent installations should include an independent hydraulic pump to raise and lower the bucket (instead of the air control valve) with actuation possible from cab and/or hopper positions. With these minor modifications, incremental newspaper collection time per stop could be halved (from 0.10 min to 0.05 min) based on simulated time studies. Initial installation costs including the recommended modifications are estimated to be about $1,700 per vehicle.

The compartmentalized approach evaluated requires a transfer ramp with a bin located below dumping grade. The alternative of dumping separately collected newspaper on the ground and either loading a storage bin manually or with the aid of a skip-loader was not deemed practical by the study participants. The ramp used during the test was constructed by the Los Angeles County Sanitation Districts and was necessarily of a makeshift variety because the Palos Verdes landfill is scheduled to reach capacity within the next three years. The ramp configuration used by the city of Newport Beach (Figure 4) accommodates two 40 cu yd roll-offs which are placed below the dumping grade. Construction cost for the concrete retaining walls, asphalt dumping surface and concrete apron on which to set the roll-offs was about $10,000.

Total startup costs are, therefore, estimated to be $10,000 plus $1,700 for each modified collection vehicle.

Performance Parameters

The compartmentalized approach to separate newspaper collection, as previously illustrated in Figure 1 and 2, incorporates a 3 cu yd storage area within a standard Shu-Pak body to isolate separately collected materials from mixed refuse. Also shown in Figure 1 is the 0.1 cu yd bucket in which to place separated newspaper bundles for subsequent mechanical loading through a bulkhead opening into the compartment for storage along the collection route. When the body has been filled with mixed refuse, the truck proceeds to the disposal site, dumps the mixed refuse first and, in an independent operation, dumps the separated newspaper at a pre-arranged location (Figure 5). As can be interpreted from this generalized sequence, incremental time is associated with collection and newspaper dumping operations. The impact of the compartmentalized approach to separate

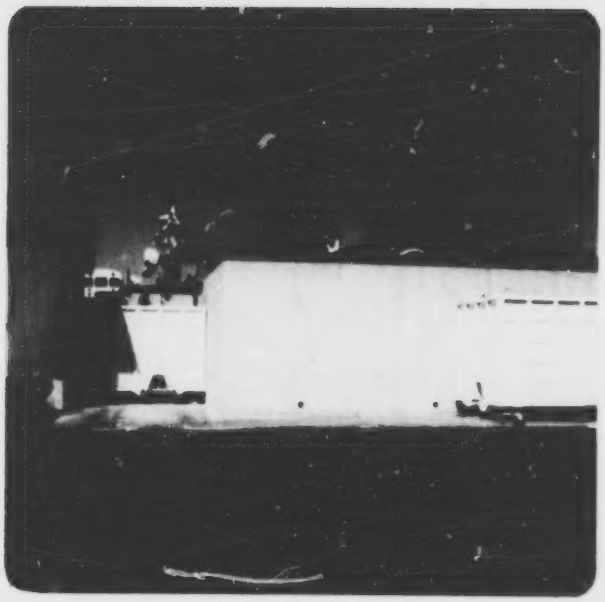

FIGURE 4. Transfer Ramp Used for Separate Newspaper Collection, Newport Beach

COLLECTION

Loading Newspaper
(bucket down)

Loading Refuse
(bucket up)

DISPOSAL

Dumping Refuse

Transferring Newspaper

FIGURE 5. Compartmentalized Truck Operational Sequence for Collection and Disposal.

newspaper collection on normal refuse loading, hauling and dumping operations in Rancho Palos Verdes is summarized below.

Driver Familiarity

The compartmentalized approach to separate collection should not offer a significant problem with regard to driver orientation.

The current prototype configuration requires the driver to take an extra step upon cab egress to actuate the air control valve to lower the bucket when separated newspapers are available. Curbside collection using a one-man crew is predicated on efficiency such that an extra step or two per stop becomes time consuming as well as irritating. Waiting for the bucket to descend or ascend is another source of irritation that results if the driver(1) fails to actuate the control upon cab egress, or (2) is not compacting at the time when the bucket must be raised to load the paper bundles. With respect to the latter condition, a slow bucket ascent may not offer sufficient velocity to eject the bundle(s) which fall into the refuse hopper during the subsequent bucket descent. These time consuming irritations can be eliminated with the addition of a cab-mounted control switch and an independent pump to raise and lower the bucket. In this manner, the driver may optimally sequence loading operations to suit the specific stop. For example, if newspapers are separately bundled/bagged and placed atop/beside refuse containers, the following sequence would be typical:

- Arrive at a collection stop.
- Engage bucket switch upon stepping out of cab.
- Walk to curbside set-out point (bucket lowers during this time).
- Pitch newspaper bundle(s) into bucket.
- Engage bucket switch and return to curb to collect refuse (bucket raises and loads newspaper into compartment during this time).
- Load refuse.
- Return to cab.

. Drive to next stop*.

Thus, the only incremental time per stop would be the time required to pitch separated newspapers into the bucket. If newspapers are not separated and placed curbside, there would be no impact on loading in that the bucket is held in a raised position until needed.

An additional advantage of the independent pump would be that the bucket cycle time (lowering and raising) can be tailored to suit driver efficiency and service area characteristics (e.g., if parked cars or mature foliage are present, the truck cannot be stopped immediately adjacent to the curb which increases the "walking" time for the driver of a one-man truck. Thus, the bucket cycle time could be slower than a situation where obstacles do not exist).

Bucket Capacity

The bucket capacity (0.1 cu yd) was designed to accommodate two large bundles (each bundle 12 inches high) or four smaller bundles (each bundle 3 to 6 inches high). In any case, if the number of bundles loaded into the bucket exceeds four, the excess will fall into the refuse hopper while being elevated to the compartment. The alternative of loading several bucket loads of newspaper per stop is viewed as being excessively time consuming. Once a separate collection program "levels out," however, and householders become accustomed to placing newspaper bundles out on a regular basis, the "overflow" problem becomes non-existent. For example, when the Rancho Palos Verdes program leveled out, an average of 1.5 newspaper bundles were generated weekly by pilot area households with 95 percent of the participating stops setting out either one or two bundles.+ With either one or two bundles the driver can pitch the bundles into the bucket. In excess of two, the driver must manually place the third and/or fourth bundles in the bucket to circumvent bundles from falling out while being elevated.

---

* When a full load of refuse is collected, the truck proceeds to the landfill, discharges the mixed refuse and proceeds to the adjacent transfer ramp to transfer the separatedly collected newspapers if the compartment is filled.

\+ Households in the Fullerton separate collection program averaged 1.7 newspaper bundles per week (Appendix B).

Loading Time

Detailed in Appendix A, four steps were taken to assess newspaper handling time on overall refuse loading time:

1) Isolation of "refuse only stops" from "separated paper stops" with data tabulated in terms of number of items per stop (newspaper bundles not included) as a function of total loading time per stop (travel time between stops not included).

2) Regression analysis performed on each data set.

3) Comparison of regression lines.

4) Deduction of actual newspaper handling time from "separated paper stop" line.

Based on this procedure, the impact of separate newspaper collection on refuse loading time for the first and second collection day of the week are respectfully shown in Figures 6 and 7. Each figure compares refuse loading time with paper* (solid line) and without paper+ (dashed line). Also shown is the hypothetical loading time (dotted line) calculated by subtracting the actual amount of time to load an average of 1.5 newspaper bundles (0.10 min) from the time for loading refuse when newspaper is separately set out. As shown in Figure 6 (first collection day), the "hypothetical line" falls below the "refuse line" leading to the conclusion that refuse containers are either lighter or easier to handle because of newspaper removal which results in a portion of the incremental paper loading time being absorbed. Although not totally, Figure 7 shows that newspaper handling time adds to refuse collection time on the second, or light collection day of the week. This dilemma is not solvable although similar data analysis of the rack program in Fullerton, California (Appendix B), supports the "absorption hypothesis." Implementing the suggested changes in the control and loading devices could further reduce the incremental time requirements by an additional 0.05 min.

Prior to the load time analysis, there was speculation that the 3 cu yd consumed by the compartment would create difficulty when trying the "break the load" after attaining 60 to 70 percent of a load. Comparison of the refuse loading time per stop during the first 60 to 70 percent of a truckload with loading time per stop during the last 30 to 40 percent yielded no significant differences.

---

* Refuse plus separated newspaper.
\+ Refuse only.

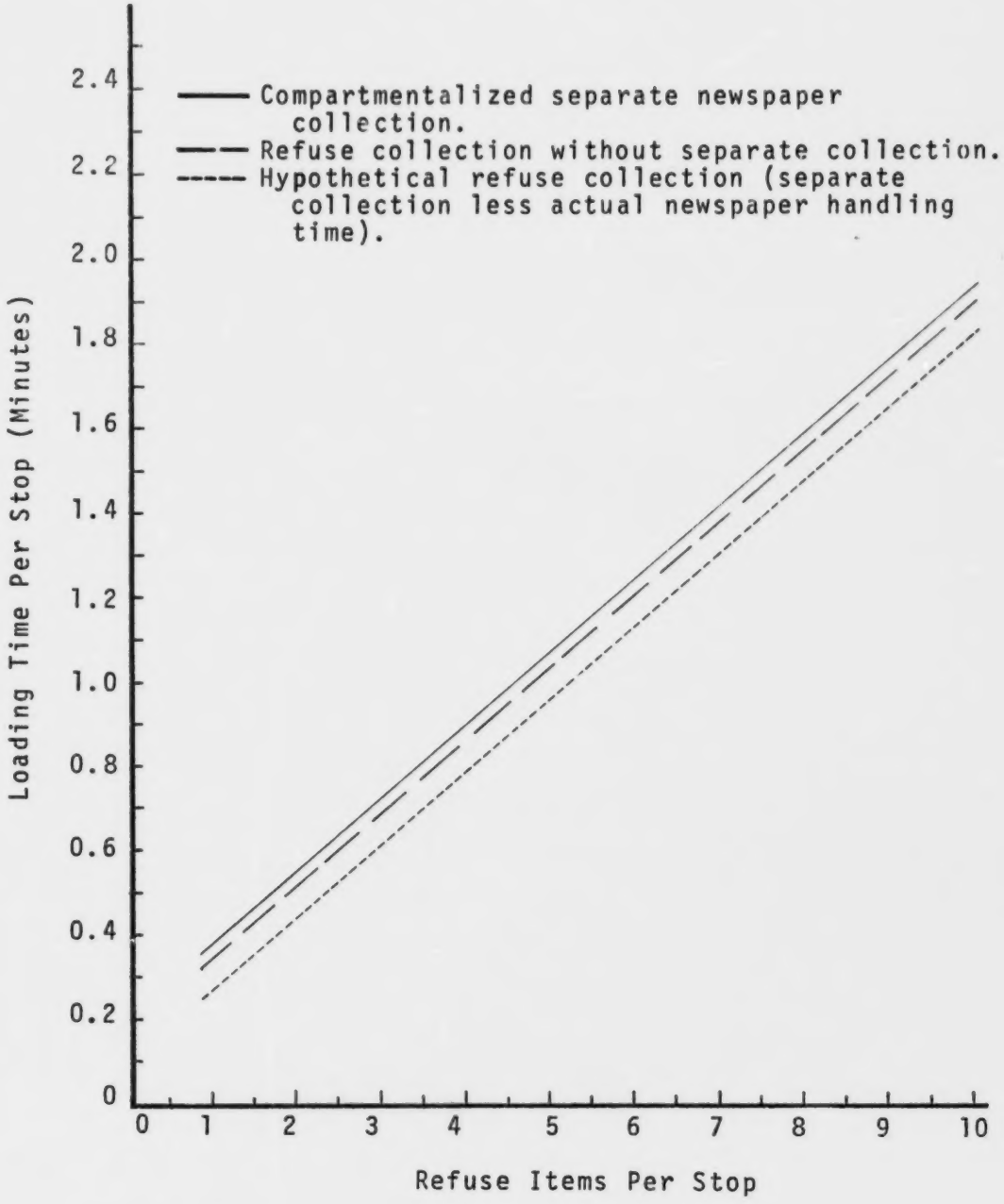

FIGURE 6. Impact of Separate Newspaper Collection on Refuse Collection; First Collection Day of Week (Compartmentalized Truck).

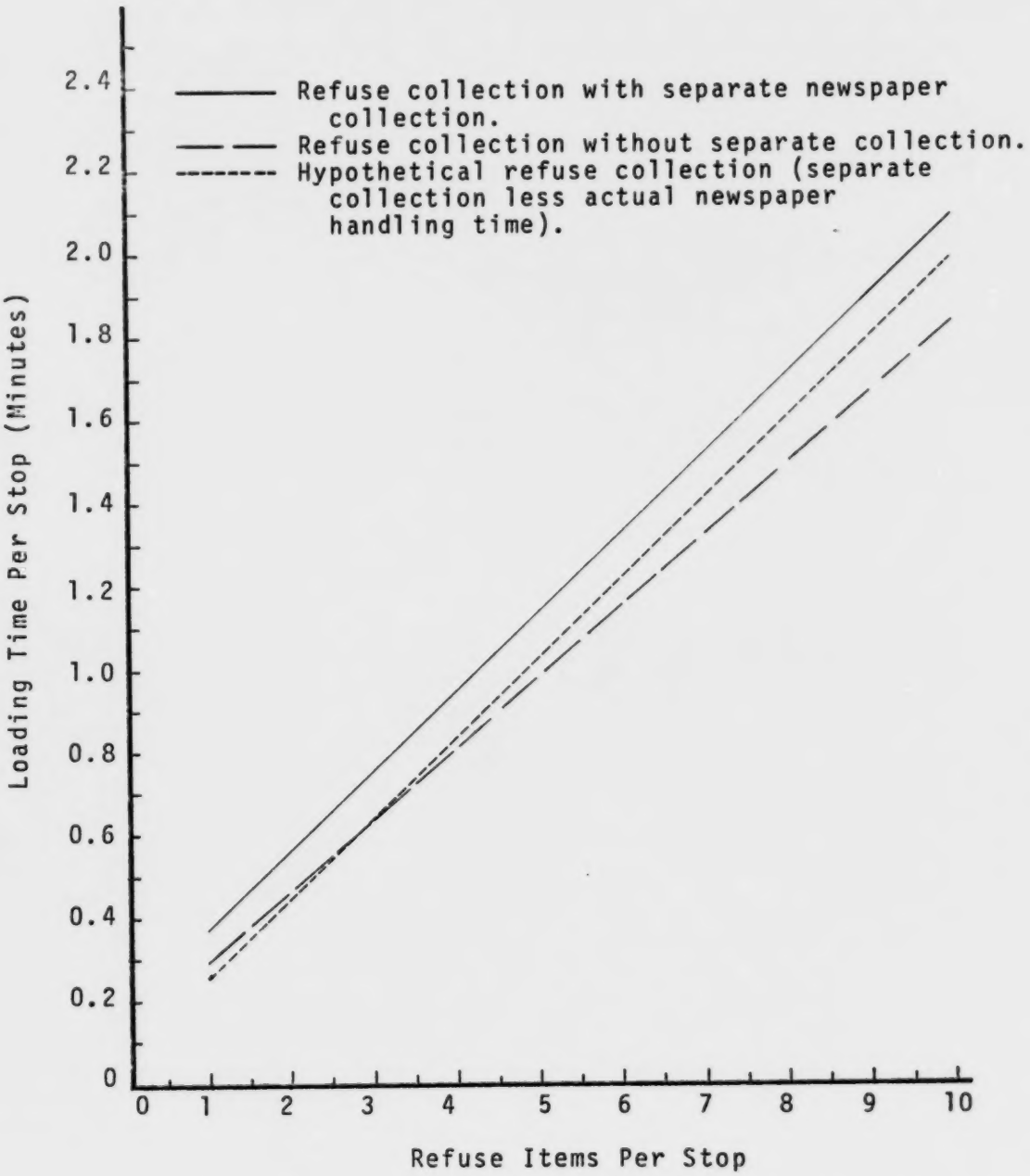

FIGURE 7. Impact of Separate Newspaper Collection on Refuse Collection; Second Collection Day of Week (Compartmentalized Truck).

Weight Distribution

The compartmentalized approach can enhance payload weight distribution (Figure 8). The total newspaper loading system (compartment structure, bucket, support, controls) adds about 700 lbs to the truck tare weight of which 400 lbs is applied to the front axle and 300 lbs to the rear. Once 900 lbs of newspapers are loaded into the compartment, however, weight on the rear axles is neutralized (fulcrum effect of taking newspaper weight out of the body and transferring it forward to the compartment). This is an important consideration in that refuse collection vehicles typically become overweight on the rear axles. Superimposed on Figure 8 are representative participation rates. At the Rancho Palos Verdes participation rate of about 35 percent, the compartment had a potential payload penalty of about 140 lbs (equivalent to refuse from about 2 households on the heavy collection day). That is, under Rancho Palos Verdes conditions, the legal gross vehicle weight of a compartmentalized vehicle would be reached 140 lbs sooner than an unmodified vehicle.

Density

Refuse Density. Installation of the compartment in the low compaction density area* of a Shu-Pak was performed to minimize load penalties due to loss of body capacity.

Refuse loads monitored before and after compartmentalization were found not to be appreciably different. In both instances, maximum loads of about 6.5 tons were attained in the compartmentalized truck. The control truck attained maximum before and after loads of about 7.0 tons. The difference in loads between the two trucks was attributed more to driver loading/compacting habits than to loss of capacity due to the 3 cu yd compartment. Accordingly, the compacted refuse density of 450 lbs/cu yd prior to

---

* Refuse loaded into a Shu-Pak is compacted from the loading hopper toward the rear doors. Once "door resistance" is met, refuse curls upward and toward the front of the body. The position of the compartment is typically a "fluff" zone, or an area where the least dense compacted refuse is located.

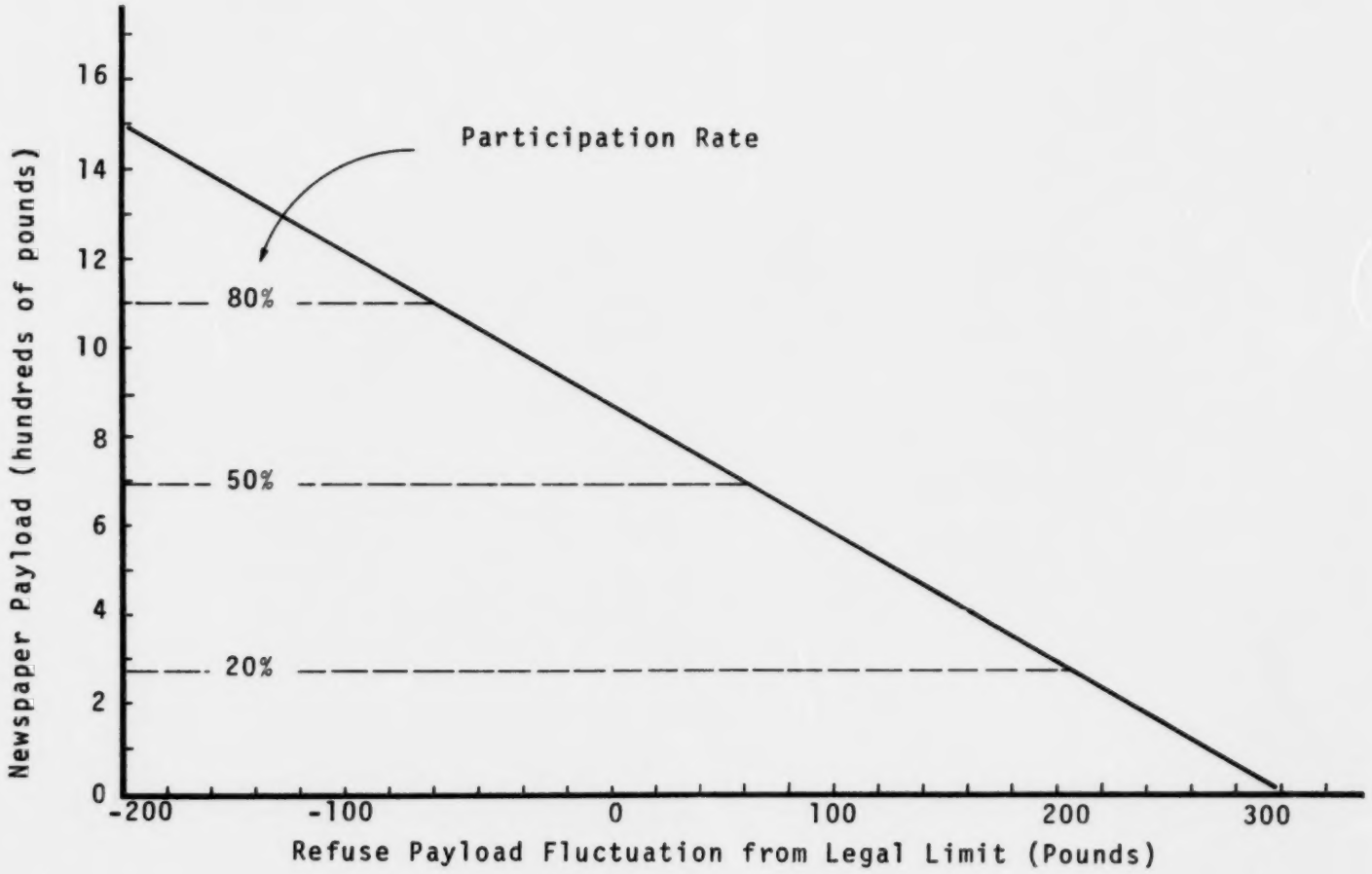

FIGURE 8. Impact of Compartmentalization on Legal Payload

modification was improved to 500 lbs/cu yd via compartmentalization without the truck exceeding legal weight limitations.

Newspaper Density. Due to the participation rate not exceeding 40 percent (20 percent on a given collection day), compartment capacity was not tested during route conditions. Accordingly, on-route density of newspaper was not estimable.

Based on tests prior to formal initiation of the separate collection program in Rancho Palos Verdes, the compartment was filled with bundled newspaper totaling 1,280 lbs. To attain this weight, however, required the driver to repeatedly stand on the loading bucket and manually rearrange the newspaper load through the bulkhead opening.* Compartment loads totaling about 1,100 lbs were attainable with minimal rearrangement.+ The latter weight converts to an in-place density of about 370 lbs/cu yd.

With the present loading technique (i.e., through top-center of the bulkhead) the angle of newspaper repose becomes more severe as the compartment fills. Truck vibration does little to overcome newspaper skin-friction when peaked near the opening. Angle of repose problems are worse yet in damp or rainy weather. An experiment to mount a probe on the bucket which would precede the newspaper bundles through the opening to knock aside peaked bundles did not perform the expectations (in fact, the probe had a tendency to catch under twine or become wedged in a bundle and pull it out of the compartment).

Newspaper Transfer Time

Rancho Palos Verdes collection routes are located within 10 miles of the Palos Verdes Sanitary Landfill. Disposal of refuse, including weigh-in, consumed an average of 15 min per load. Driving time to the transfer ramp, positioning and dumping the separately collected newspaper into a roll-off bin and return to the access road required an average incremental time of 5 min.

---

* Although questionable from a safety standpoint, the rearranging procedure is similar to procedures required to add water to the auxiliary engine radiator when necessary (i.e., climbing in the hopper area).

\+ The approximate point where manual rearranging is required was not determined during the study.

Cooperation of the Los Angeles County Sanitation Districts provided a nearly optimal solution to newspaper transfer. Had the transfer facility been at a location other than the disposal site, incremental time requirements would have been correspondingly greater.

Newspaper Contamination

When dumped, separately collected newspaper comes in contact with the interior of the collection vehicle body. Newspaper contamination was considered a potential problem. However, mixed residential refuse typically has a high paper content (even with newspaper removed). The scouring action of this paper, and in the test area, large quantities of yard trimmings and brush resulted in the body floor being sufficiently clean to impart no noticeable contamination upon newspaper bundles.

Program Economics

Similar to the rack approach, the compartmentalized approach also allows mixed refuse and separated newspaper to be loaded coincidentally by the same crew and, in the case of a Shu-Pak, in the same hopper area (Figure 9). Accordingly, householder refuse set-out habits need not be significantly altered. In order to be cost-effective, however, the compartmentalized and rack approaches must be capable of absorbing incremental newspaper collection and transfer time without necessitating additional equipment and labor.

The separate truck approach entails the use of independent equipment and labor to collect separated newspaper (Figure 10). Depending on the ability of a collector to divert labor and equipment from normal or reserve refuse collection forces, the frequency of separate collection may be varied.

The cost of separate newspaper collection and the economic impact on mixed refuse collection operations depends on a number of factors including: separate collection approach, equipment type and size, crew size, collection frequency, participation rate, haul time, and revenue/diverted disposal savings. By using Rancho Palos Verdes service area conditions, mixed refuse collection frequency, refuse generation rate, newspaper generation rate, etc., a hypothetical residential area of 10,000 single family homes was evaluated using a refuse collection model (Appendix E). Supportive data (Appendix D) were derived from BFI operations in Rancho Palos Verdes (Appendix A); MG Disposal operations in Fullerton (Appendix B) where

FIGURE 9. Rack Approach to Separate Newspaper Collection.

FIGURE 10. Separate Truck Approach to Separate Newspaper Collection.

Shu-Paks are used to separately collect newspaper using the rack approach; and Newport Beach municipal operations (Appendix C) where Shu-Paks are used to collect newspaper via the separate truck approach.

Model Economics for Separate Collection

The alternative separate collection approaches were evaluated on the following assumptions:

- Compartmentalized and rack approaches were evaluated in conjunction with efficient mixed refuse collection systems where no additional time requirements could be absorbed without additional equipment and labor.
- In the analysis of the separate truck approach, mixed refuse collection vehicles were re-routed to compensate for the reduced waste quantities due to separate collection.

Figures 11 through 16 depict the economic viability of the alternative separate collection approaches based on Rancho Palos Verdes conditions. The bounds on each figure reflect newspaper revenue rates of $8 per ton (upper bound) and $25 per ton (lower bound). Included in the savings is a constant $2 per ton for diverted disposal costs. Also plotted for comparative purposes is the estimated baseline cost for mixed refuse collection prior to implementation of a separate collection program.

Compartmentalized Approach. Figure 11 is representative of the equipment as tested (incremental loading time of 0.10 min per participating stop). Figure 12 assesses the cost sensitivity to the suggested equipment changes based on an incremental time reduction of 0.05 min per stop.

The impact of reducing incremental newspaper loading time is visibly evident by comparing the upper bound between the two figures. With an incremental load time of 0.10 min per participating stop, the $8 per ton revenue rate is barely adequate to cover the additional cost for labor and equipment to implement the program. By halving the incremental time (Figure 12), even an $8 per ton revenue is more than sufficient to cover the additional costs.

As seen in both figures, the compartmentalized concept effectively reduces overall collection costs until a 75 percent participation rate is attained. At this point under Rancho Palos Verdes conditions, the compartment and

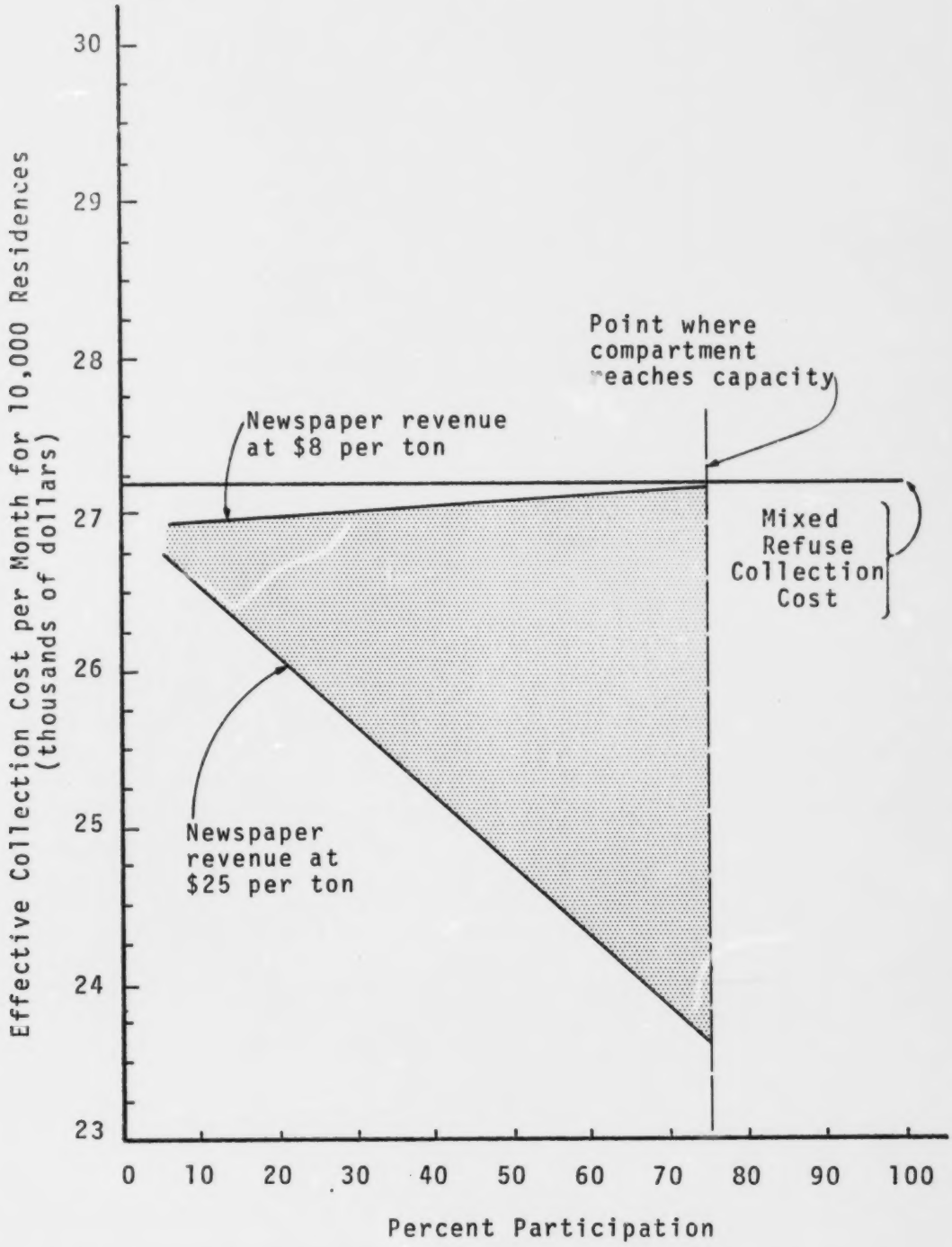

FIGURE 11. Effective Cost for Compartmentalized Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis

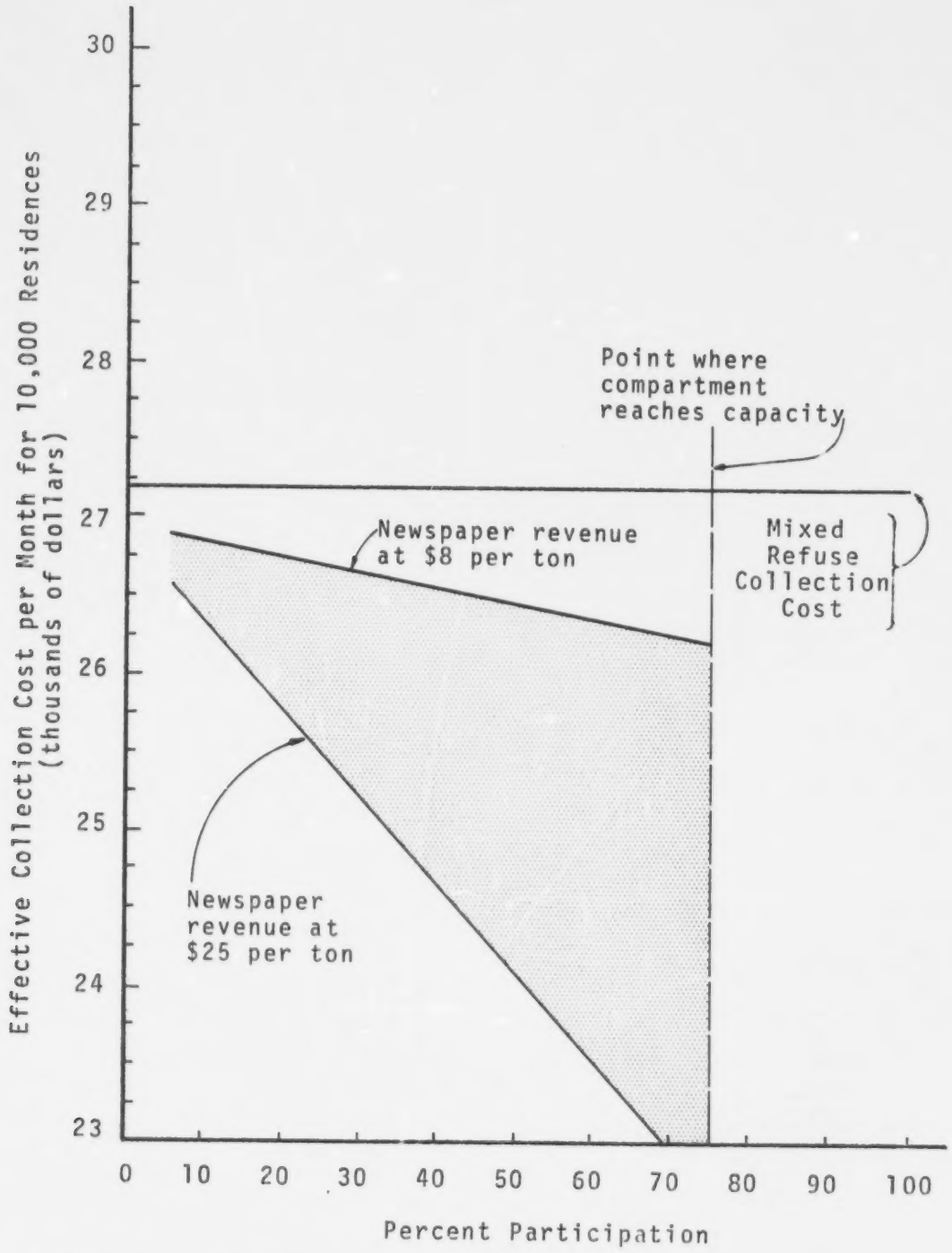

FIGURE 12. Effective Cost for Compartmentalized Collection of Separated Newspaper Pending Recommended Equipment Modifications

truck are both filled to capacity. When participation exceeds 75 percent a larger compartment must be installed to enable simultaneous filling of compartment and body.

Due to lack of community support or "competition" from schools, religious groups, etc., participation rates exceeding 60 percent are highly unlikely. Thus, the 75 percent limitation in Rancho Palos Verdes was deemed appropriate.

Rack Approach. The discontinuities shown on Figure 13 delineate points (35 and 70 percent participation) where on-route transfer of newspaper is required. At these points, an incremental cost increase is incurred to cover transfer costs. With newspaper revenue at $8 per ton, savings exceed collection costs when participation is 70 percent or less.

The economics of the rack approach are similar to the compartmentalized approach, as tested (Figure 11).

Separate Truck Approach. Figures 14 through 16, respectively, indicate the economics for implementing the separate truck approach for separate collection frequencies of once per week, once every two weeks, and once per month. As seen, cost is sensitive to collection frequency which reflects the quantity of newspaper available per participating stop (i.e., at once per week, the driver would collect 13 lbs per stop; at bi-weekly or monthly frequencies, the driver would respectively collect 26 or 56 lbs). Thus, economies of scale are evident.

Comparing separate truck approach costs with those of the compartmentalized approach shows that the latter approach is preferable at either weekly or bi-weekly frequencies. At a once per month separate collection frequency the compartmentalized approach is preferable under 50 percent and similar from 50 through 70 percent participation. Beyond 70 percent, the separate truck is the best choice although participation rates exceeding 50 percent are infrequent.

Conclusions. The compartmentalized approach as evaluated appears to be a viable separate collection option provided a newspaper transfer facility is located at the disposal site or adjacent to the haul route. Economics can be further improved with the recommended equipment changes. The capacity of the compartment can be specified for local needs based on expected participation rates and quantity of available newspaper.

Studies of the rack approach using rear loaders with side mounted racks, have found incremental newspaper collection times of 10 to 15 seconds per stop can be absorbed into normal collection activities without necessitating additional equipment or labor. It is reasonable to assume that the smaller incremental time requirements associated with the compartmentalized approach using a Shu-Pak, can be similarly absorbed.

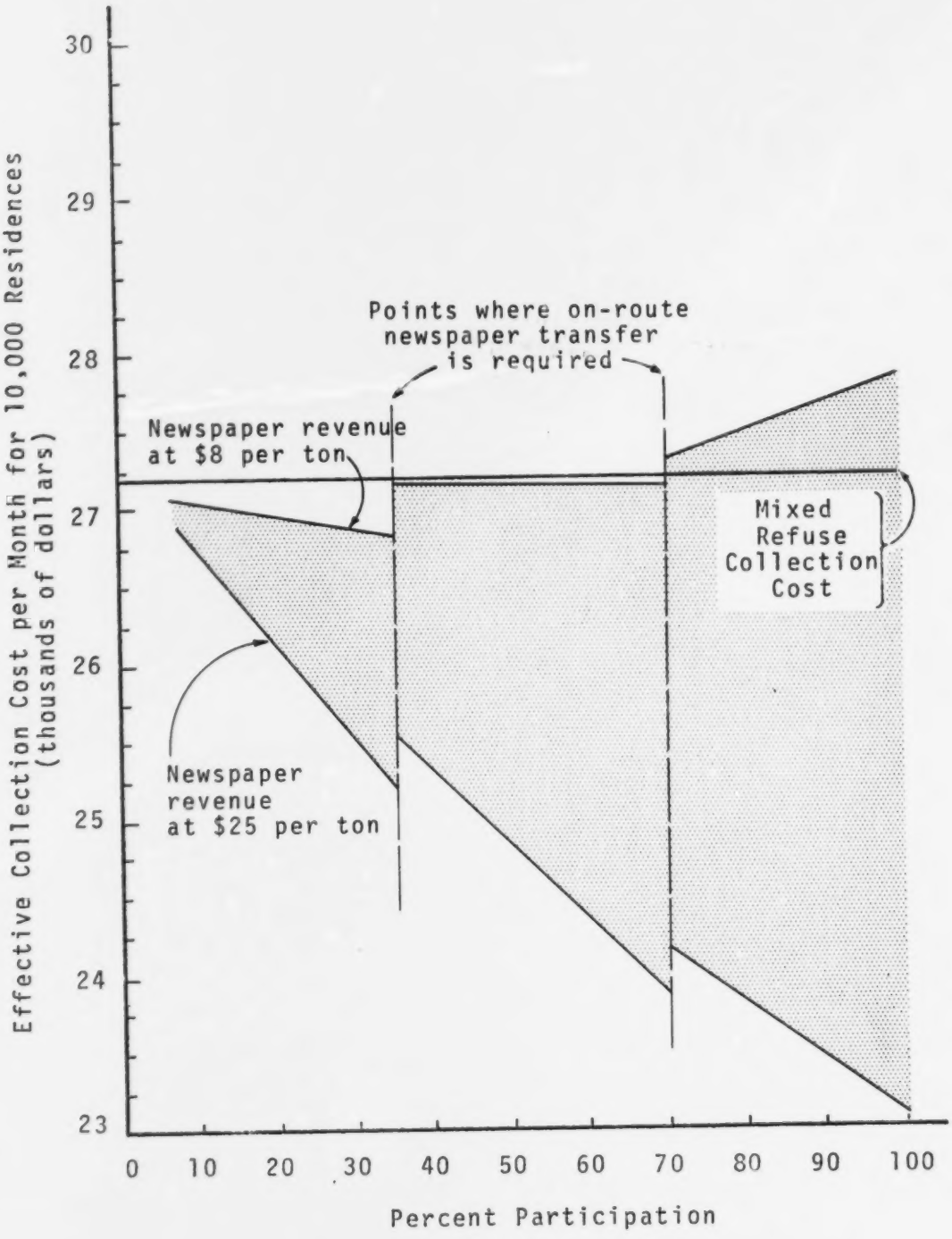

FIGURE 13. Effective Cost for Rack Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis

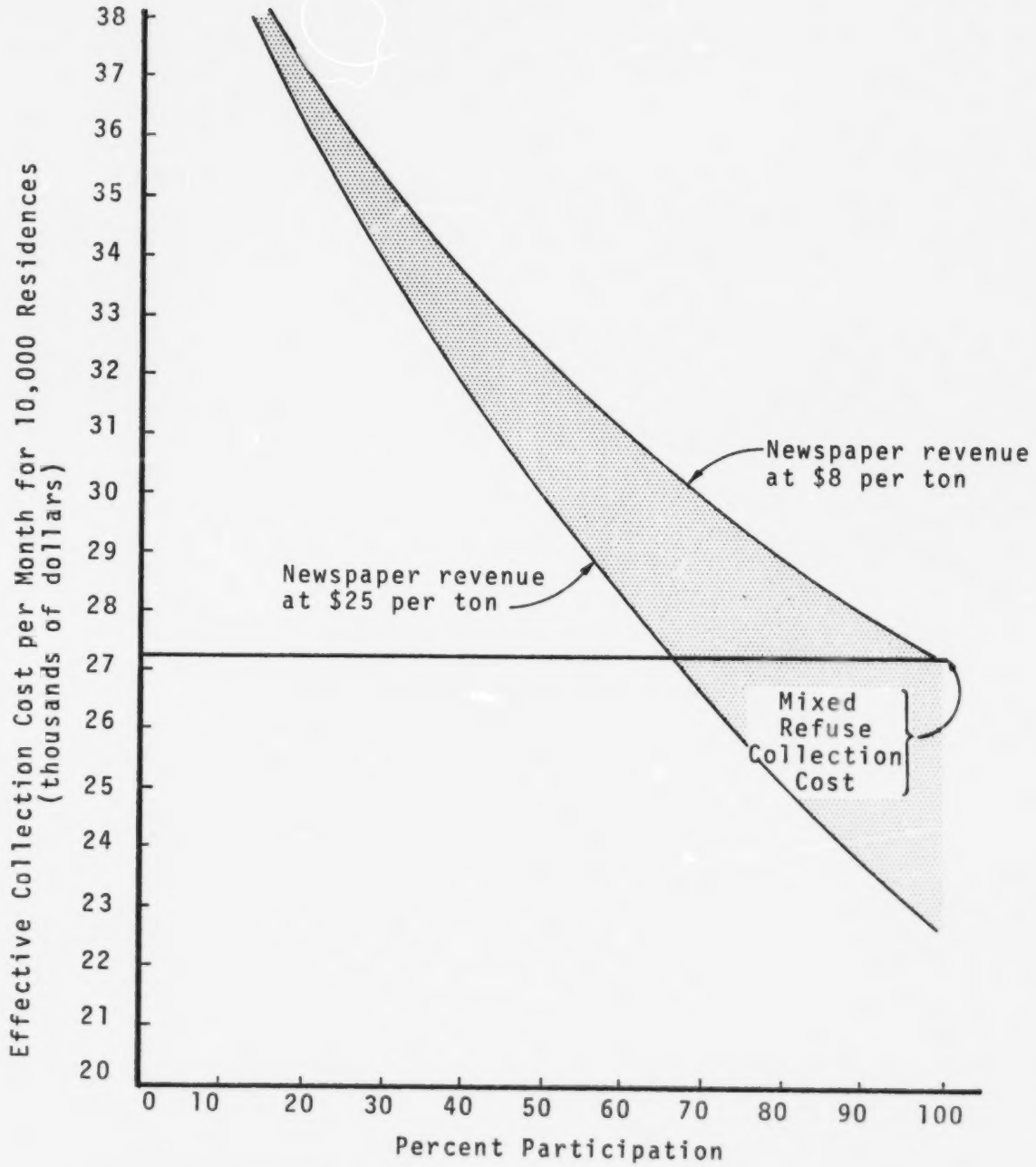

FIGURE 14. Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/wk Separate Collection.

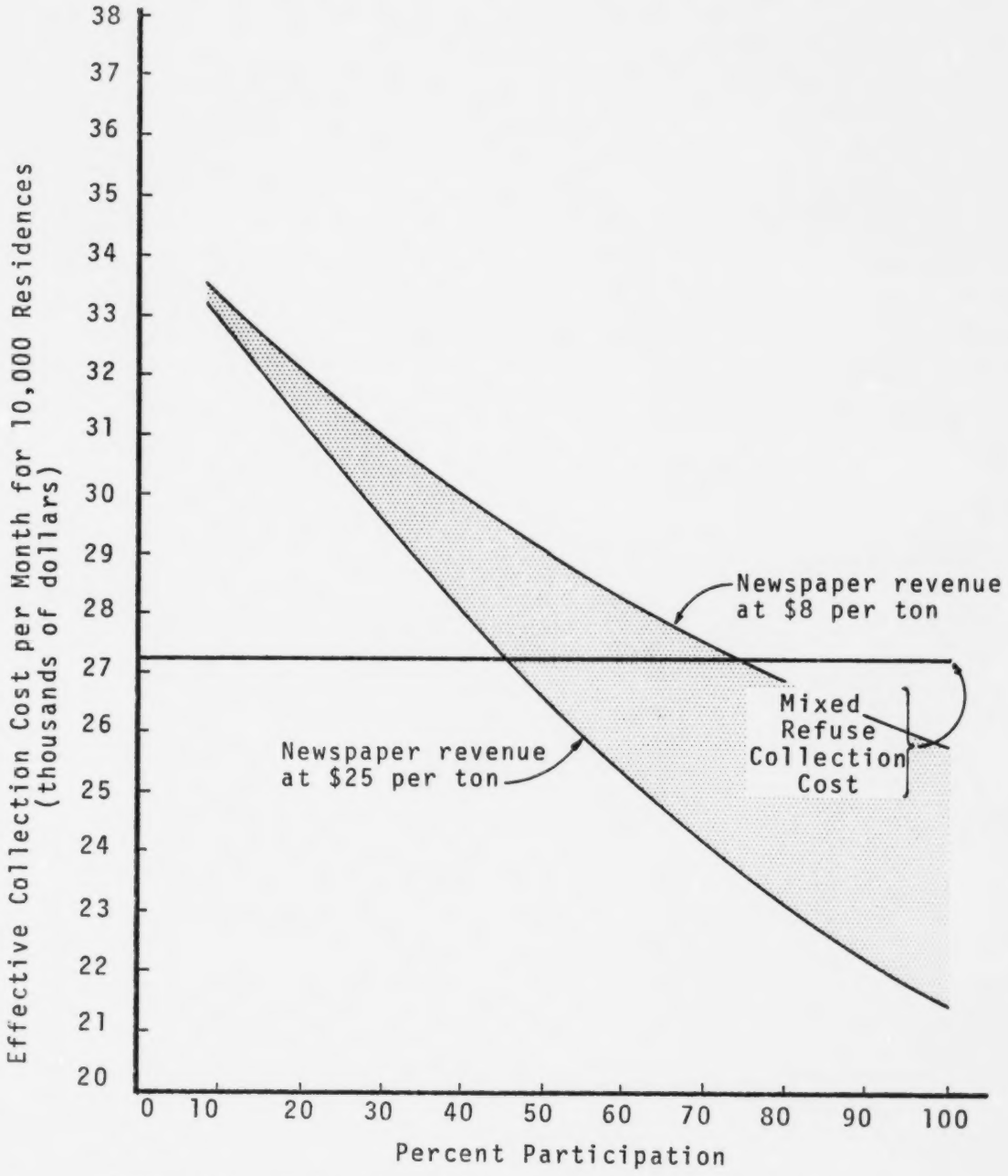

FIGURE 15. Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/2 wk Separate Collection.

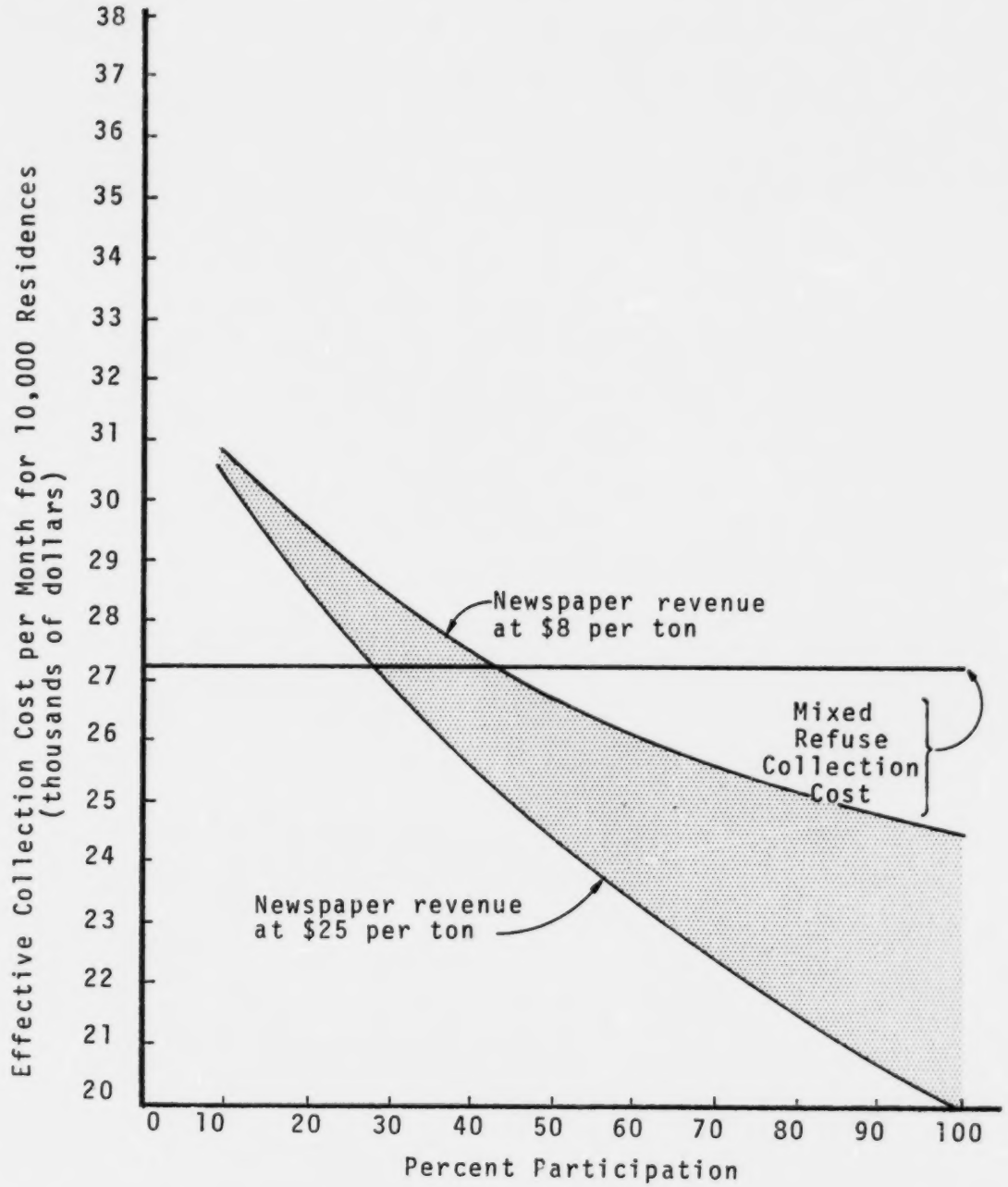

FIGURE 16. Effective Cost for Separate Truck Collection of Separated Newspaper Versus Mixed Refuse Collection Cost Prior to System Implementation: Exemplary Analysis, 1/mo Separate Collection.

V

ACKNOWLEDGEMENTS

We gratefully express our appreciation to the Resource Recovery Division of the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency. In particular, we commend Ms. Penelope Hansen, Project Officer, for her support of the evaluation and for her sincere interest in seeking methods to optimize separate collection of recyclable materials.

Special recognition is made to the many participants who made the study possible. Individually, we express our gratitude to Browning Ferris Industries, Inc. for permitting a collection vehicle to be modified and allowing the subsequent testing and evaluation to be performed; to Maxon Industries for installing the compartment and associated equipment and controls without cost to the study or participants; to the City of Rancho Palos Verdes for supporting the test program; to the Palos Verdes Chapter of the American Association of University Women for providing in-kind public relations support; to the Los Angeles County Sanitation Districts who voluntarily built a transfer ramp at the Palos Verdes Landfill to facilitate unloading of separately collected newspaper; and to MG Disposal and the City of Newport Beach who respectively provided sites to study rack and separate truck approaches to separate newspaper collection.

Preceding page blank

APPENDICES

Appendix		Page
A	Rancho Palos Verdes, California	A-1
B	Fullerton, California	B-1
C	Newport Beach, California	C-1
D	Systems Analysis Data Development	D-1
E	Collection Model	E-1

Preceding page blank

APPENDIX A

RANCHO PALOS VERDES, CALIFORNIA

The city of Rancho Palos Verdes has a population of about 39,000. Of this sum, about 7,700 persons residing in approximately 2,200 single-family homes receive twice weekly refuse collection service from Browning Ferris Industries, Inc. (BFI). The "BFI collection area" in which the separate newspaper experiment was performed is characterized by homes on large lots (average street frontage of 93 ft) on steep hills (up to 20 percent grades).

DATA DEVELOPMENT FOR PROGRAM EVALUATION

The basic methodology employed to evaluate the compartmentalized approach to separate collection was to monitor the collection vehicle before and after modification. Based on the monitoring performed, data were developed to assess the impact on normal refuse collection operations and to assess economic viability. The second BFI truck ("control truck") with similar routes in Rancho Palos Verdes was also monitored to aid in determining if any measurable impact was influenced by the prototype concept or by collection area idiosyncracies such as seasonality of waste generated, variation in number and/or type of containers collected per residence, etc.

The remainder of this appendix presents the data gathered and analyzed during the course of the study.

Collection/Disposal Operations

With the exception of brush trimmings, mixed residential refuse is stored primarily in metal/plastic containers and/or plastic bags. Brush is bundled and set out at the curb with containerized refuse for collection. Collected refuse is transported to the Palos Verdes Sanitary Landfill operated by the Los Angeles County Sanitation Districts.

Implementation of the pilot separate collection program altered the general collection/disposal format only to the extent that (1) separated newspaper was collected simultaneously with mixed refuse, and (2) separated newspaper was discharged into a roll-off container located adjacent to the working face at the Palos Verdes Landfill via a transfer ramp constructed by the Los Angeles County Sanitation Districts.

Refuse Per Stop. The frequency distribution of refuse items* per stop before and after commencement of the separate collection program are shown for the compartmentalized truck in Figures A-1 and A-2 and for the control truck in Figures A-3 and A-4; each set respectively depicting the first and second collection day of the week.

Load Time. Loading time per stop was assessed by following each vehicle along the route. The modified truck was monitored for two weeks prior to compartmentalization and an equal amount of time after the separate collection program commenced. The control truck was monitored for two-day periods during the same time frames. Loading time was recorded at each stop and an item count made. The aggregated results of the time studies are displayed in Figures A-5 through A-10 for the compartmentalized truck and in Figures A-11 through A-13 for the control truck. The load time line was established using linear regression with data input weighted by frequency of occurrence.

Figures A-5 through A-7 present the loading time characteristics for the compartmentalized truck on the first collection day of the week, Figures A-8 through A-10 on the second day. Each set depicts the following: the first graph of the series displays loading time prior to the separate collection program. The second and third graphs show the relationship after commencement of separate collection; the second graph depicts stops where no newspaper was set out, and the third graph depicts stops which participated in the program by separating newspaper. In each case, the relationship is expressed in terms of refuse items. In this manner, the time to handle separated newspaper can be assessed on a common basis.

Travel Time Between Stops. Travel time between stops remained constant at about 0.30 min before and after vehicle modification.

Newspaper Characteristics

Newspaper Quantity. A weekly newspaper generation rate of 13.0 lbs per household in the pilot area was based on the quantities collected during field studies conducted after

---

* Storage containers, disposable bags, and/or bundled refuse; does not include newspaper bundles.

the program had attained normalcy in weekly set-out patterns.* This rate was deemed reasonable for the pilot area based on the following rationale:

- A pre-program survey conducted by the American Association of University Women reached 62 percent of the 1,100 pilot area residents. One question in the survey sought to determine which newspapers were received by pilot area residents. Using these data and individual publisher weight per issue estimates resulted in a newspaper generation rate of 10.7 lbs per household per week. This estimate was believed to represent a lower bound for two reasons: (1) much of the local "junk mail" is printed on newsprint, and (2) local "advertising newspapers" are delivered weekly without subscription (these newspapers would likely not be considered by a householder when responding to a questionnaire).

- A 1972 household solid waste separation study conducted for two weeks by 50 pilot area families,+ resulted in a newspaper generation rate of 14.8 lbs per household per week. This estimate was considered an upper bound based on recent efforts by the majority of newspaper publishers to reduce the quantity of newsprint used due to escalating purchase costs.

As shown in Figure A-14, the number of newspaper bundles set out per participating stop ranged from one to five with an average of 1.5.

---

* At program onset, residents set out quantities of newspaper that had been stored for several weeks or months.

\+ Unpublished case study of the Palos Verdes Recycling Center conducted by SCS Engineers in April, 1973, in support of: SCS Engineers. Analysis of Source Separate Collection of Recyclable Solid Waste: Collection Center Studies. [v. 2]. Environmental Protection Agency, 1974 [75 p.]. (Distributed by National Technical Information Service, Springfield, Va., as PB-239 776.)

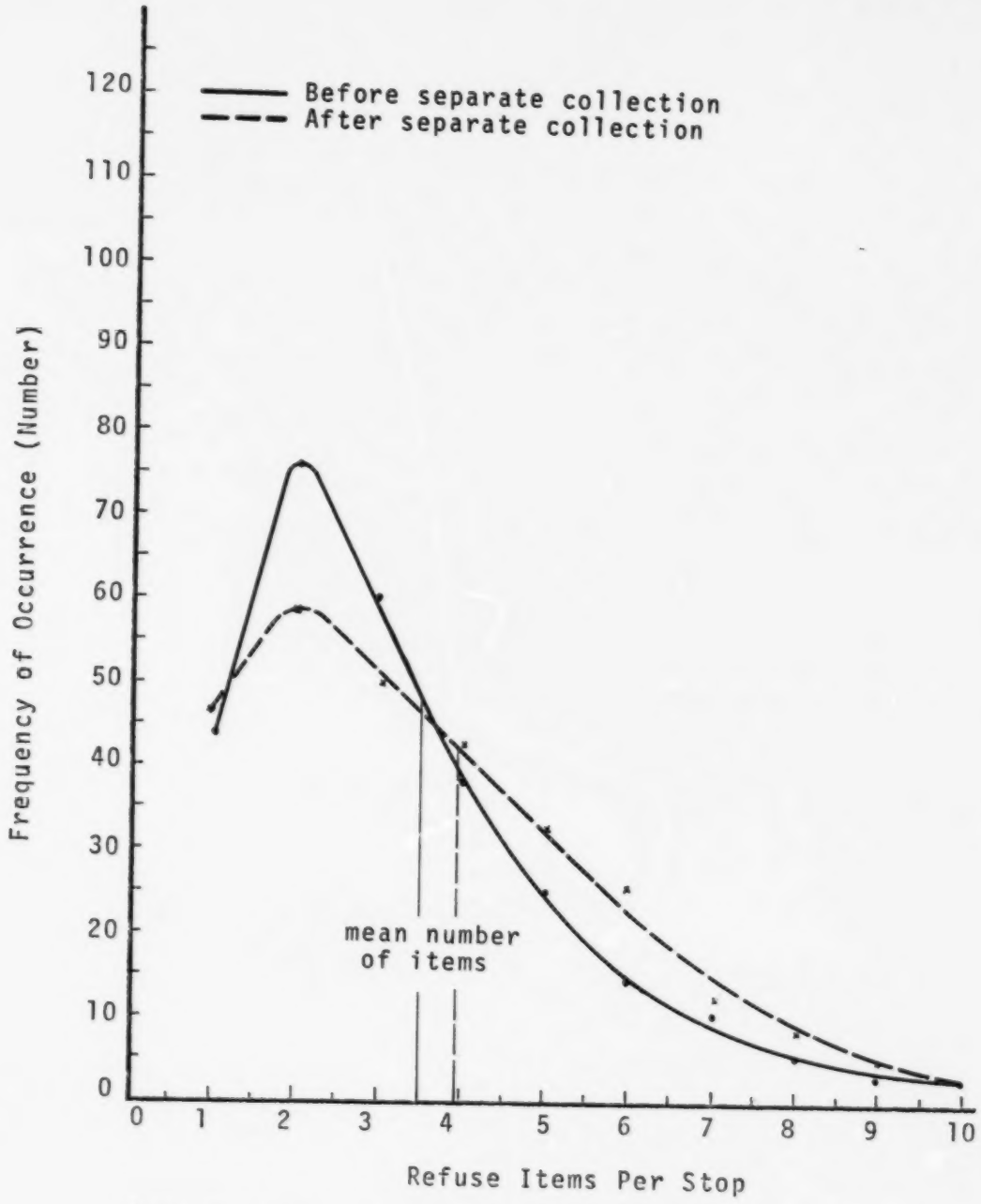

FIGURE A-1. Frequency Distribution of Refuse Items per Stop; First Collection Day of Week (Compartmentalized Truck)

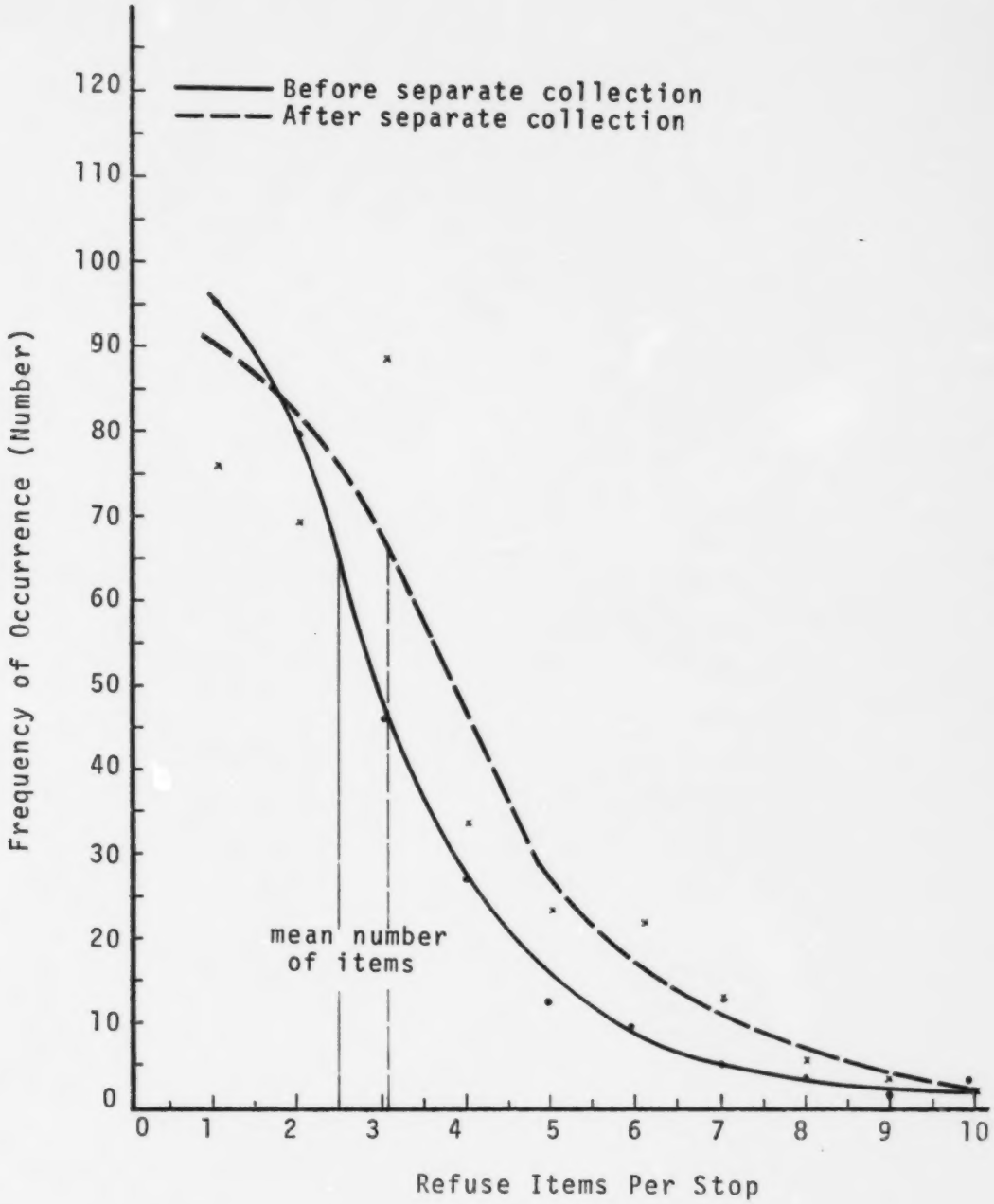

FIGURE A-2 . Frequency Distribution of Refuse Items per Stop; Second Collection Day of Week (Compartmentalized Truck)

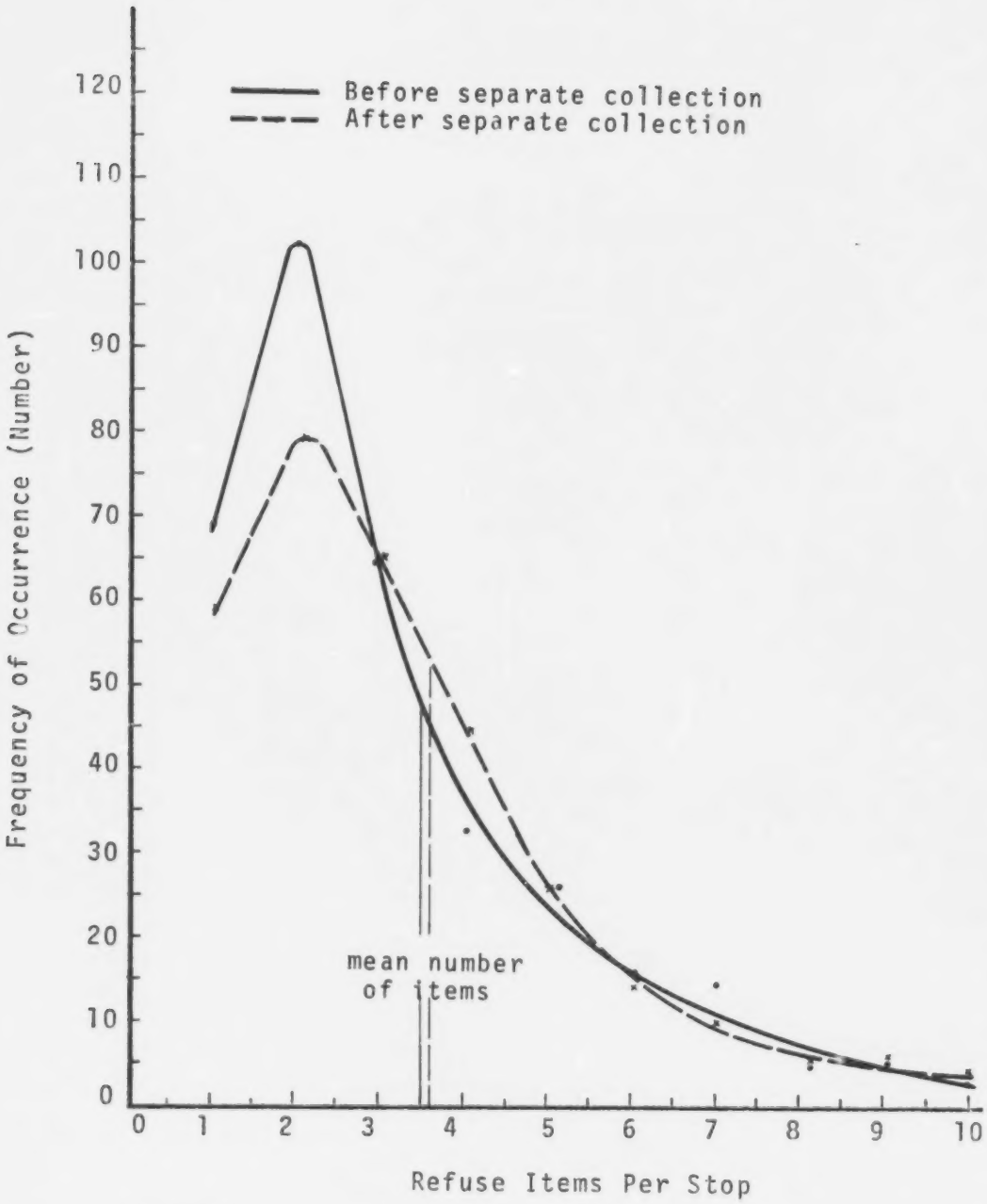

FIGURE A-3 . Frequency Distribution of Refuse Items per Stop; First Collection Day of Week (Control Truck)

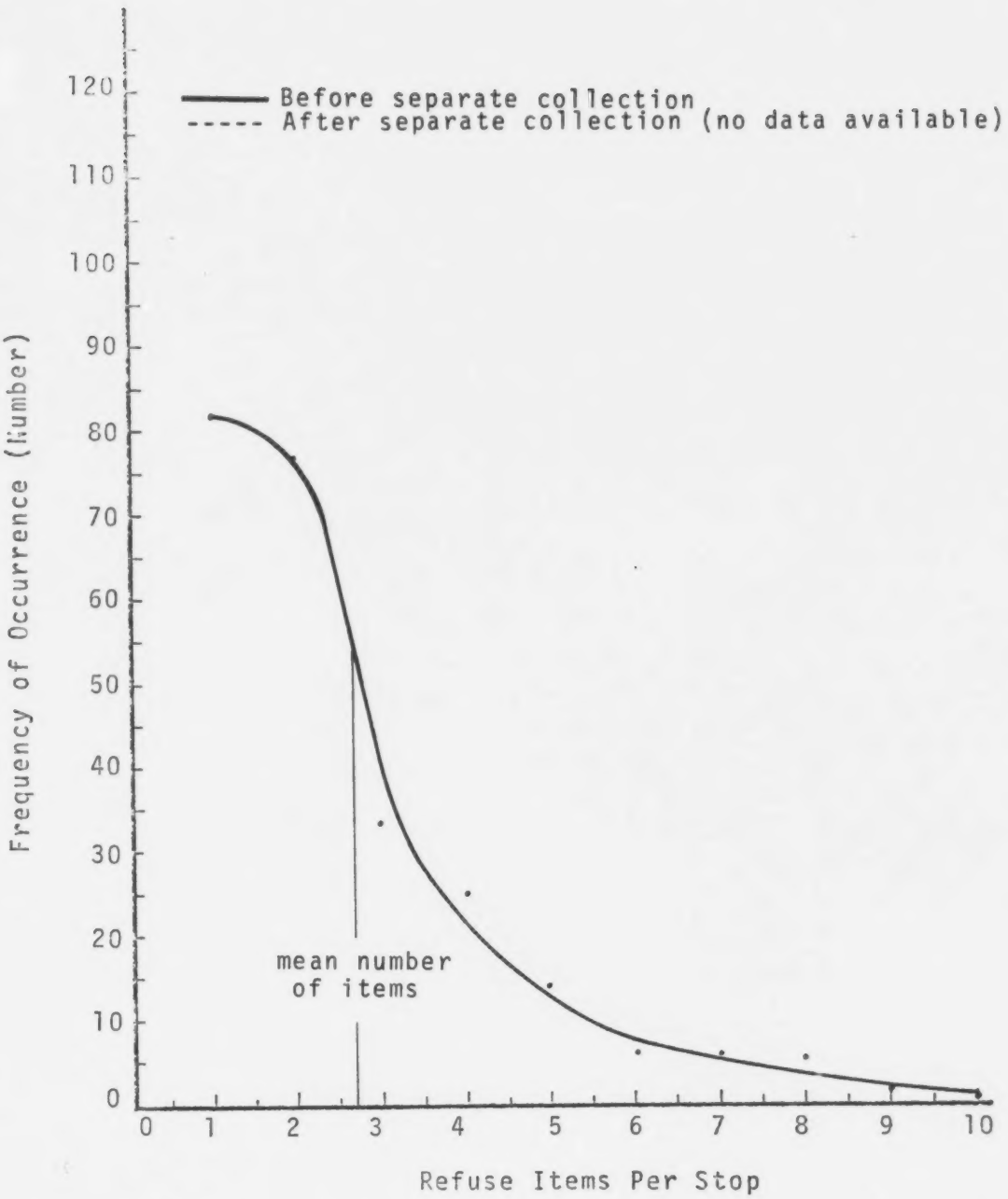

FIGURE A-4 . Frequency Distribution of Refuse Items per Stop; Second Collection Day of Week (Control Truck)

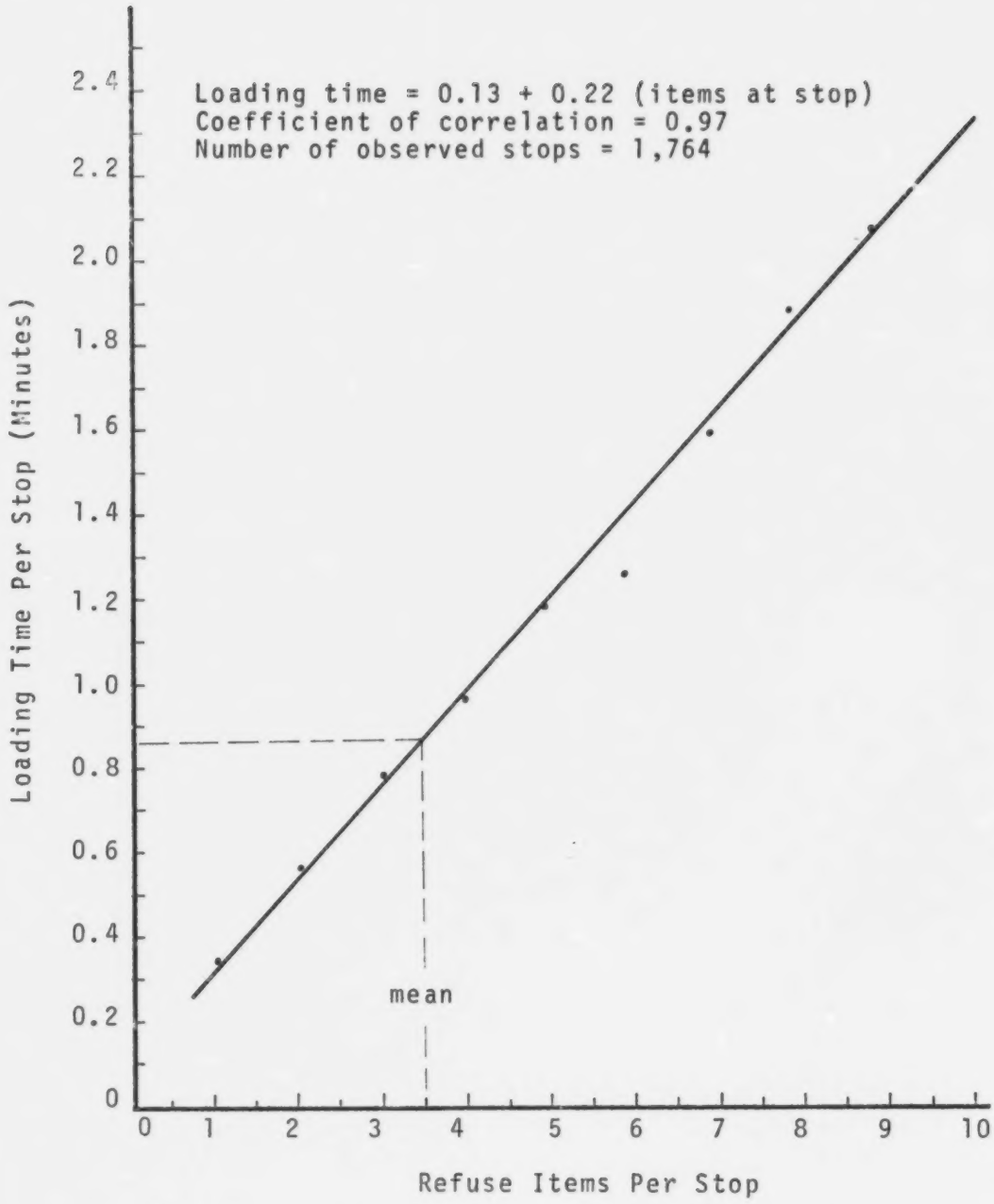

FIGURE A-5 . Loading Time as a Function of Refuse Items per Stop Prior to Commencement of Separate Collection Program; First Collection Day of Week (Compartmentalized Truck).

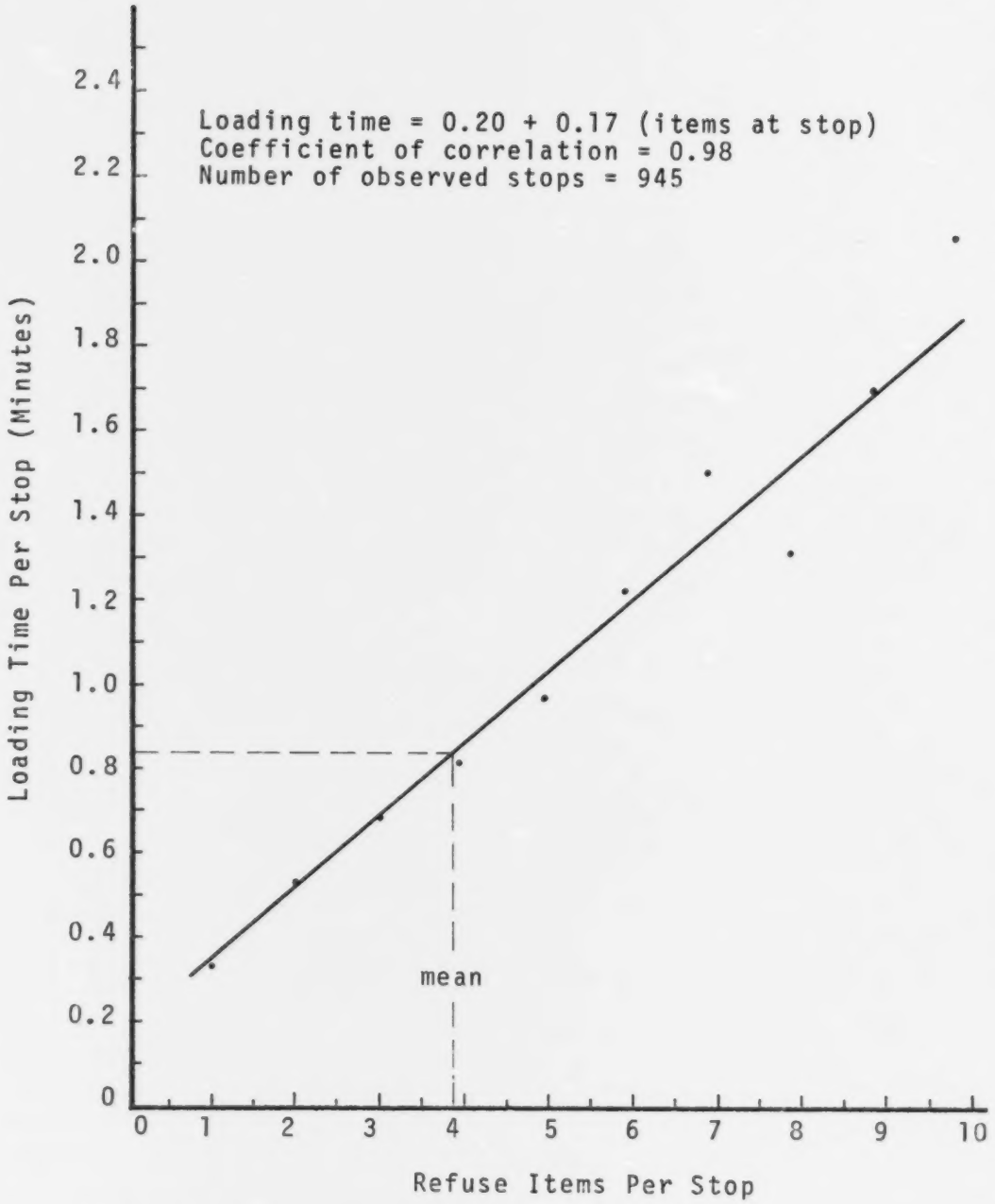

FIGURE A-6 . Loading Time as a Function of Refuse Items per Stop After Commencement of Separate Collection; First Collection Day of Week (Compartmentalized Truck - Refuse Only Stops).

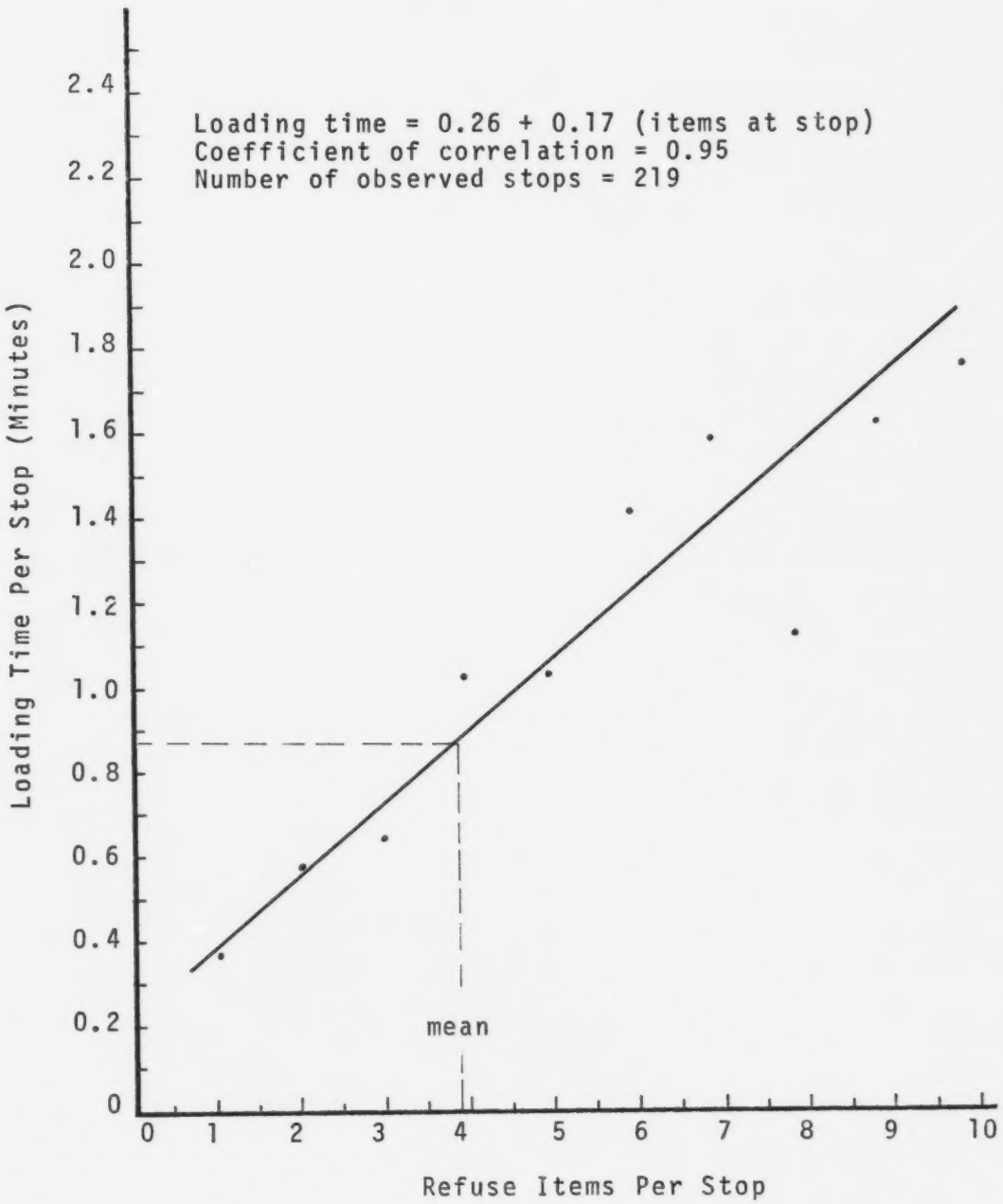

FIGURE A-7. Loading Time as a Function of Refuse Items per Stop After Commencement of Separate Collection; First Collection Day of Week (Compartmentalized Truck - Separated Paper Stops).

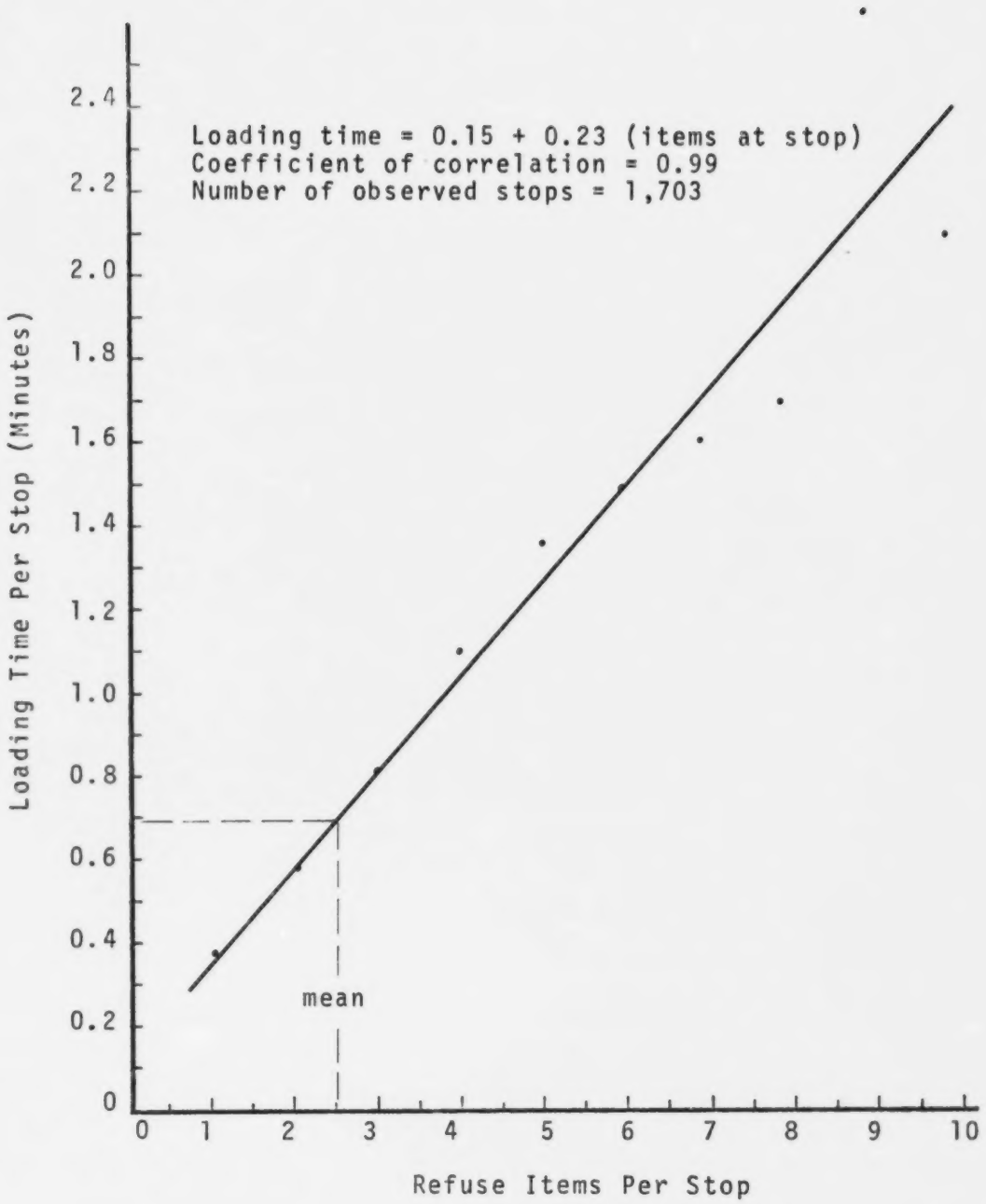

FIGURE A-8 . Loading Time as a Function of Refuse Items per Stop Prior to Commencement of Separate Collection Program; Second Collection Day of Week (Compartmentalized Truck).

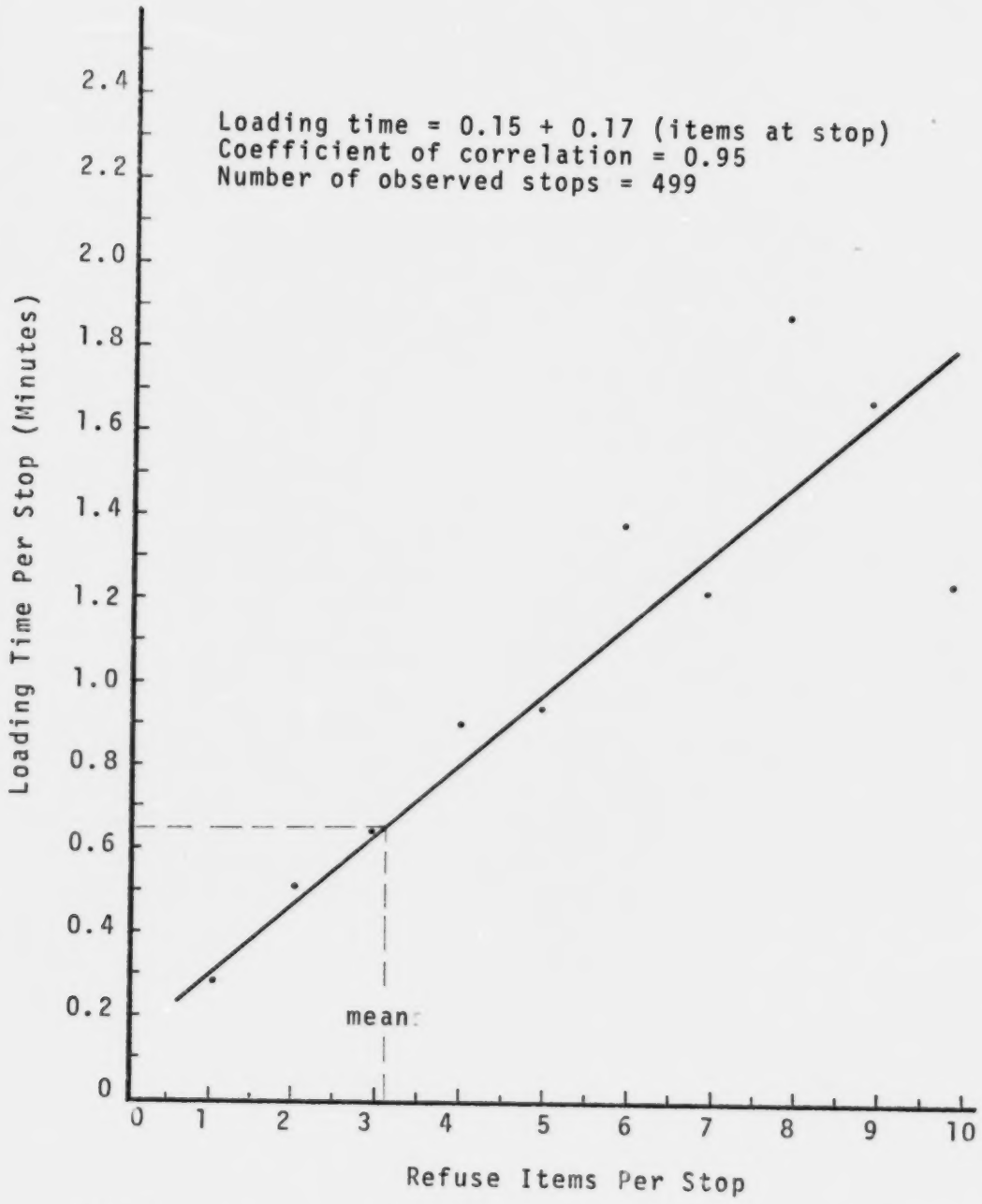

FIGURE A-9. Loading Time as a Function of Refuse Items per Stop After Commencement of Separate Collection; Second Collection Day of Week (Compartmentalized Truck - Refuse Only Stops).

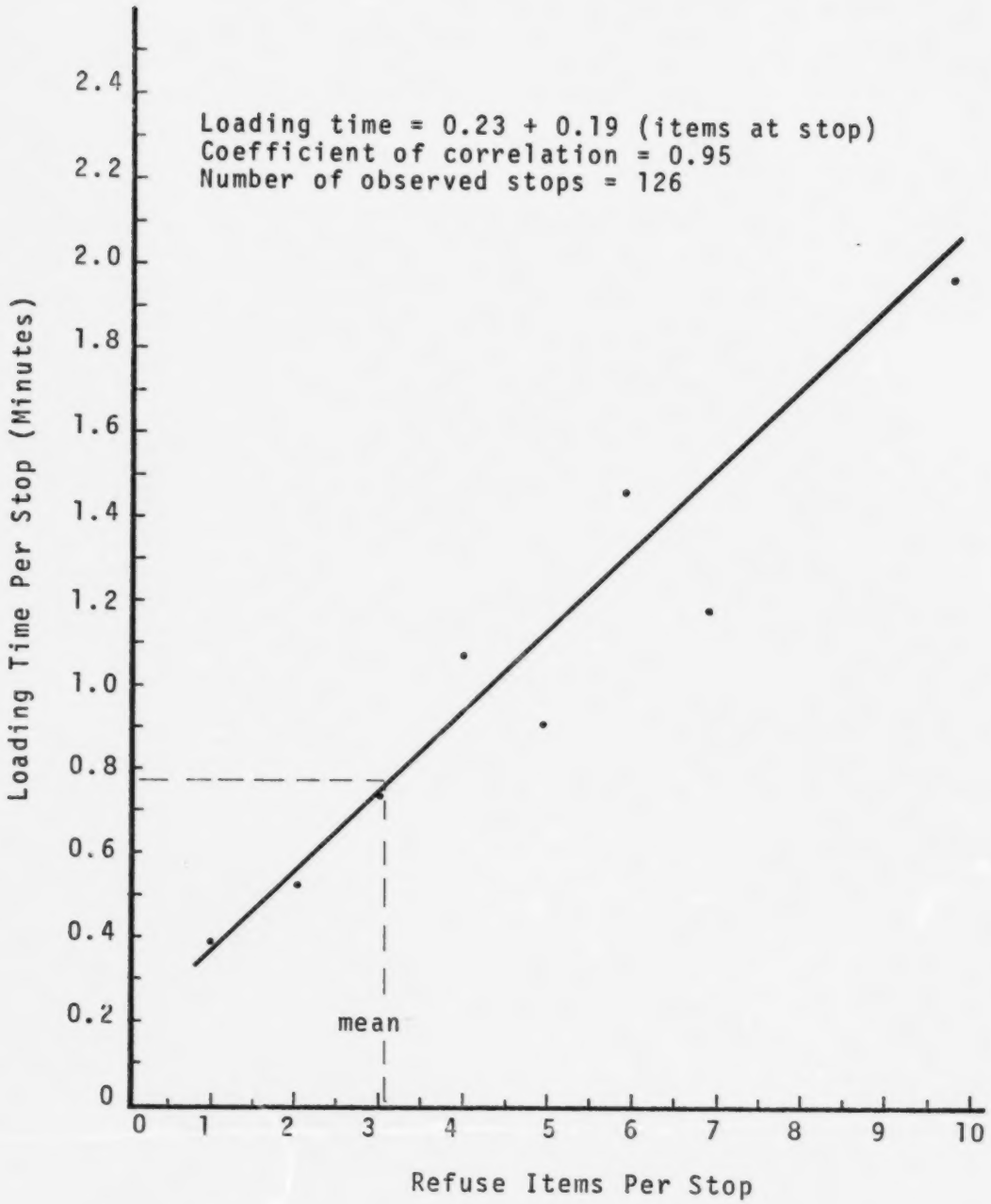

FIGURE A-10. Loading Time as a Function of Refuse Items per Stop After Commencement of Separate Collection; Second Collection Day of Week (Compartmentalized Truck - Separated Paper Stops).

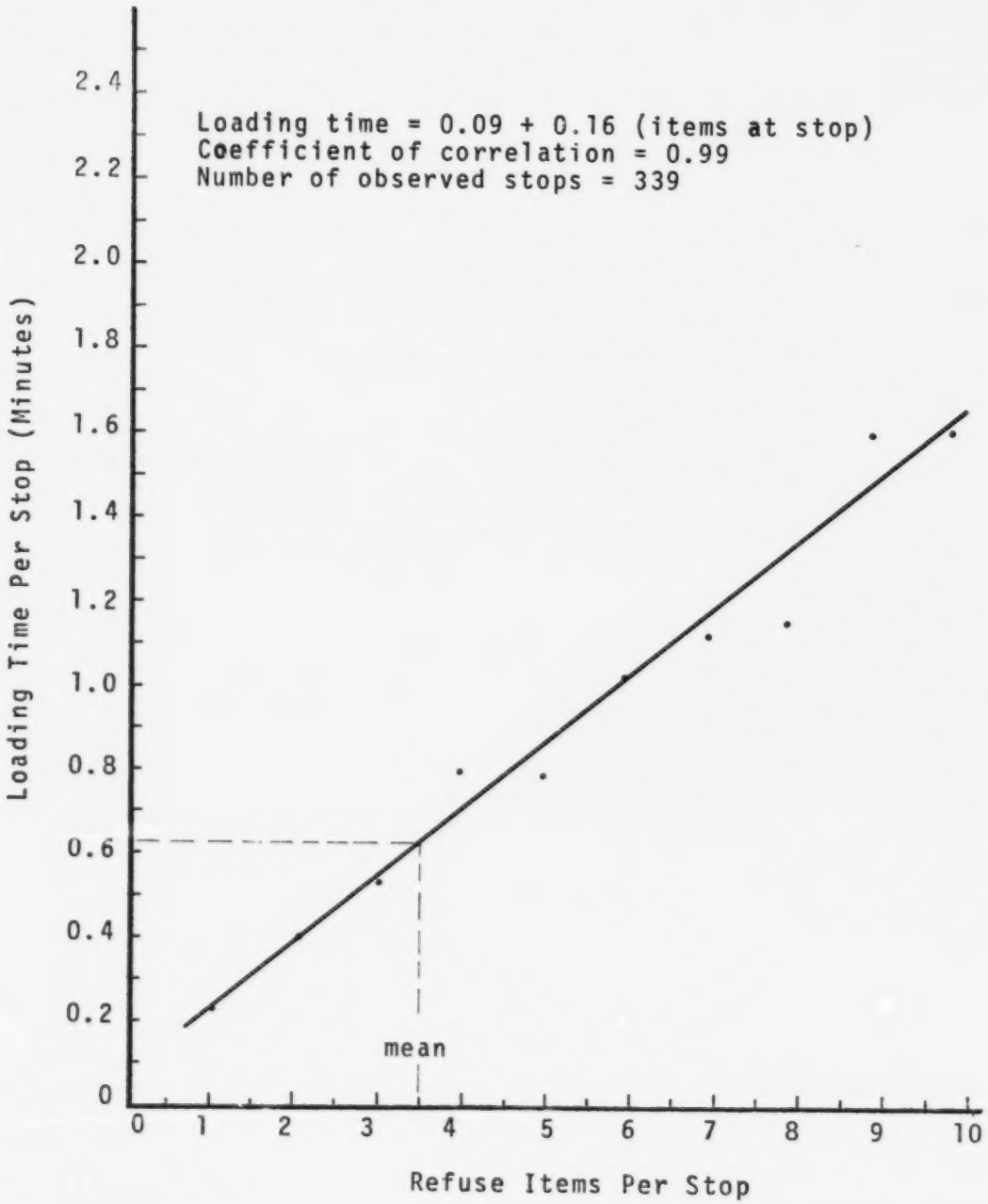

FIGURE A-11 . Loading Time as a Function of Refuse Items per Stop Prior to Commencement of Separate Collection Program; First Collection Day of Week (Control Truck).

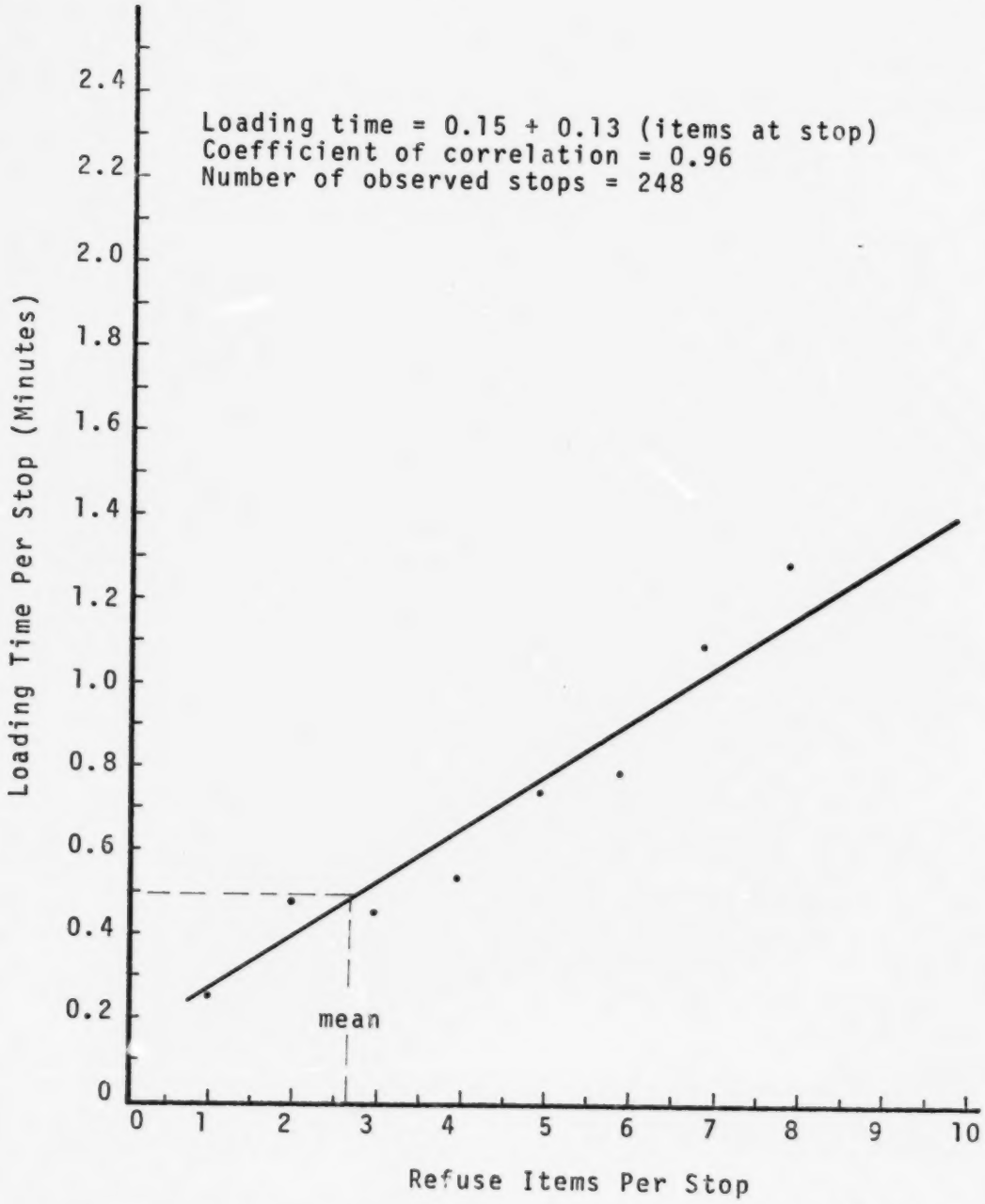

FIGURE A-12. Loading Time as a Function of Refuse Items per Stop Prior to Commencement of Separate Collection; Second Collection Day of Week (Control Truck).

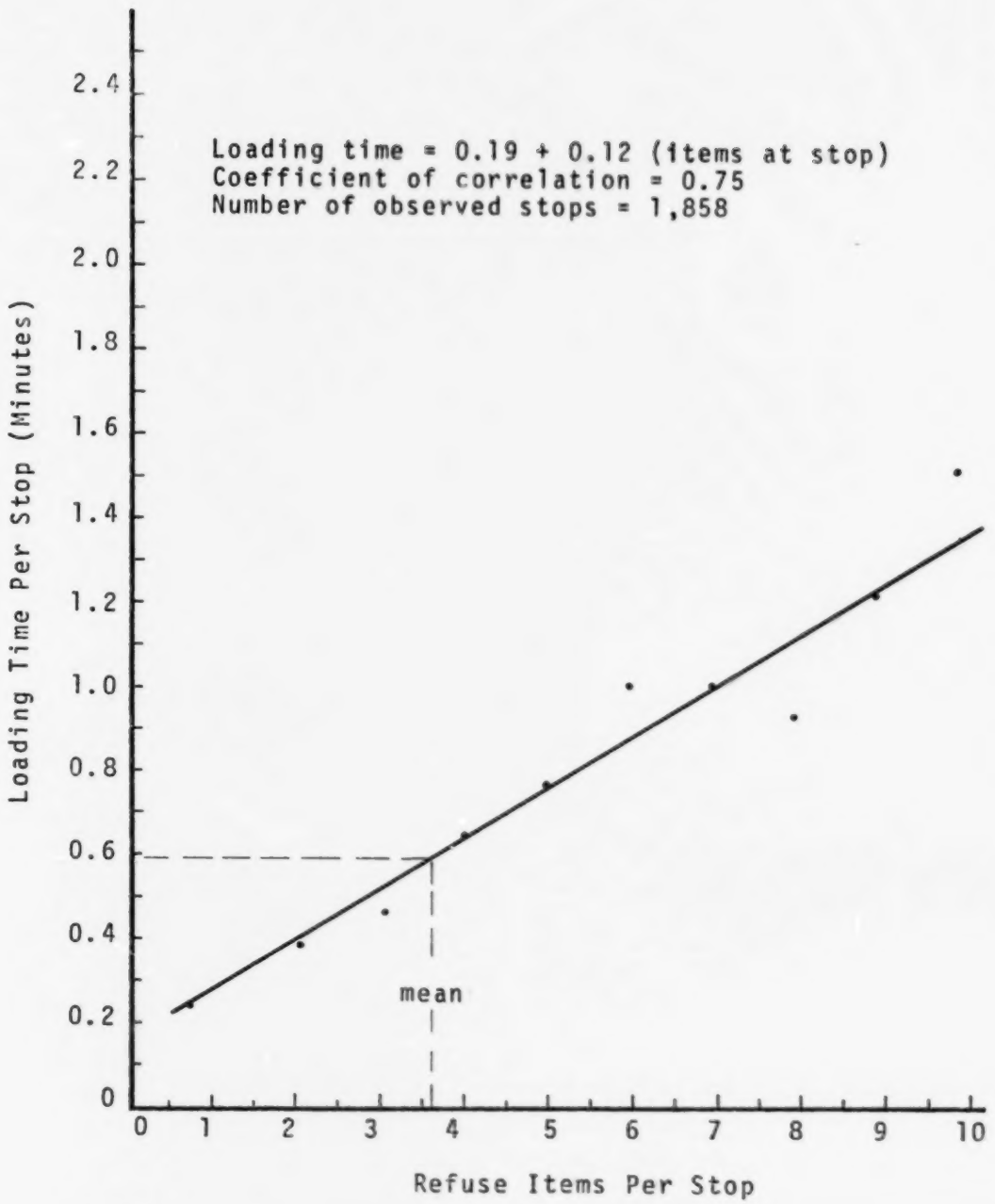

FIGURE A-13. Loading Time as a Function of Refuse Items per Stop After Commencement of Separate Collection; First Collection Day of Week (Control Truck).

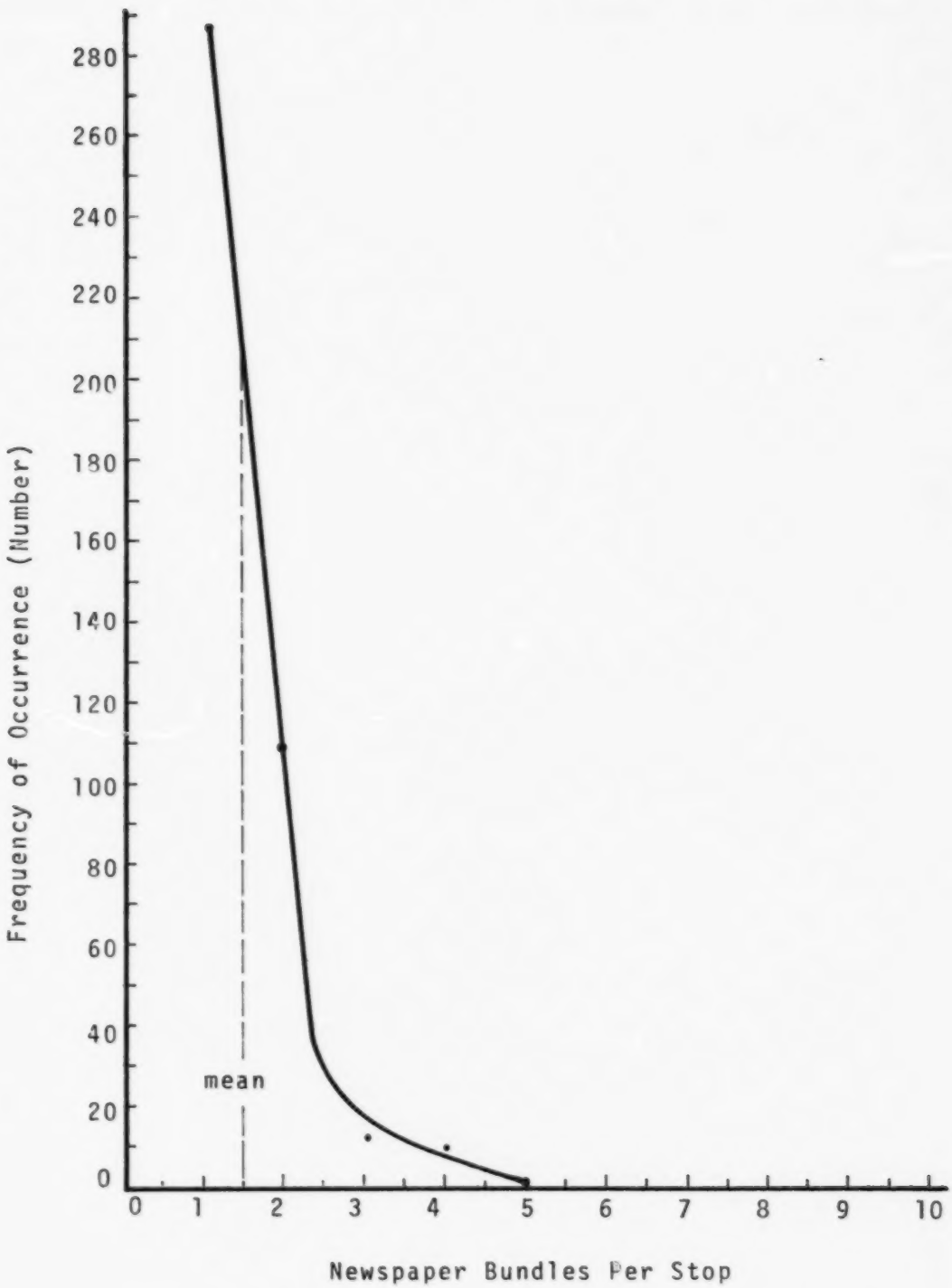

FIGURE A-14. Frequency Distribution of Newspaper Bundles per Stop during Field Studies

APPENDIX B

FULLERTON, CALIFORNIA

The City of Fullerton is located 25 miles southeast of Los Angeles and has a population of about 82,000. Fullerton initiated curbside separate collection of newspaper in September, 1973. After soliciting bids for collection and marketing of separate newspaper, a one-year contract was signed with a local paper dealer to provide once per month service using an open stake truck and a three-man crew. At the end of the year period, the paper dealer opted not to renew the contract. At this time, MG Disposal, the private hauler in Fullerton, agreed to retrofit their residential refuse collection vehicles with racks ($500 per vehicle) to separately collect newspaper on a weekly basis concurrent with normal refuse collection. As shown in Table B-1, the response to weekly separate collection doubled the sums collected during the monthly program.

MG Disposal uses the Shu-Pak, one-man collection vehicle for residential service. In order to minimize the incremental paper handling time associated with a rack approach, a 1.5 cu yd rack was mounted in the hopper area, directly opposite the right-hand loading sill (Figure B-1). Removing the flexibility of loading from the left side of the truck was not critical in Fullerton as loading is performed only from the right-hand side. Sequentially, the driver arrives at a collection stop, picks up the bundled paper, tosses it across the hopper area into the rack (Figure B-2) and commences loading mixed refuse. Based on a one-day study of one collection route, the rack held bundles from about 35 homes. Using the observed average of 1.7 bundles collected per home and assuming the average bundle to weigh 9 lbs*, each full rack-load weighs about 540 lbs with a corresponding in-place density of approximately 360 lbs/cu yd. When the rack fills, newspaper is off-loaded into the route foreman's pick-up truck for transfer to MG Disposal's yard. The offloading effort is aided by a full-length, hinged door on the back of the rack which is flush with the left side of the truck. This configuration enables the pick-up truck to be positioned alongside the collection vehicle for ease of transfer. The average transfer operation required 5 minutes.

---

*Based on Rancho Palos Verdes data; see Appendix A.

TABLE B-1

QUANTITIES OF NEWSPAPER SEPARATELY COLLECTED
FULLERTON, CALIFORNIA

Month	Quantities of Newspaper Per Month (tons)		
	1973	1974	1975
January	--	25	115
February	--	55	90
March	--	48	105
April	--	65	69+
May	--	44	50+
June	--	47	63
July	--	36	64
August	--	36	--
September	42*	40*	--
October	66	127	--
November	N/A	113	--
December	N/A	115	--

N/A Not available.

*From September, 1973 through September, 1974, monthly collections were made by local paper dealer. From October, 1974 to present, weekly collections made by MG Disposal.

+Collection personnel on strike.

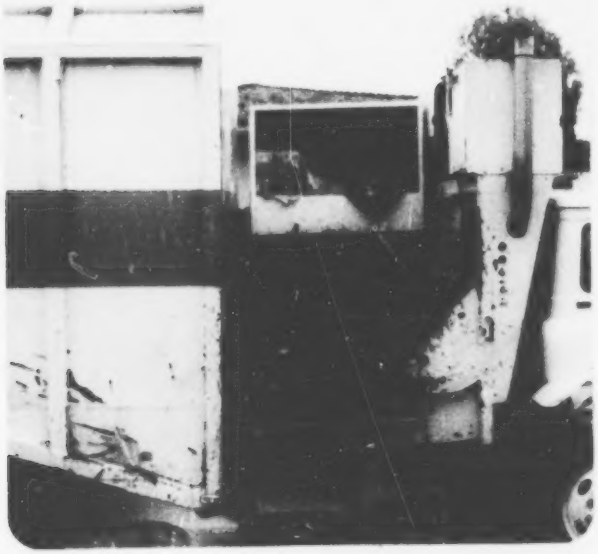

FIGURE B-1. Rack Mounted in Shu-Pak Hopper Area

FIGURE B-2. Loading Separated Newspaper in Rack

Time-studies were conducted to quantify the impact of separate collection on normal refuse collection operations. The results of the one-day study are graphically displayed in Figures B-3 and B-4. Figure B-3 depicts the actual paper loading time in terms of time as a function of the number of bundles collected per stop. Figure B-4 compares the refuse loading time of "refuse plus paper" stops (solid line) to the "refuse only" stops (dashed line). Also shown is the hypothetical loading time (dotted line) calculated by subtracting the actual amount of time to load 1.7 bundles of newspaper (route average) from the time for loading "refuse plus paper." As shown, the "hypothetical line" falls below the refuse only line leading to the conclusion that containers are either lighter or easier to handle due to newspaper removal which results in a portion of the incremental paper loading time being absorbed. In terms of the time studies conducted, the average incremental route time to handle separated newspaper is 0.08 min per stop with paper versus 0.13 min that would be concluded for loading 1.7 bundles if only Figure B-3 were considered.

The loading time equations for Figure B-4 were derived via linear regression and are shown below:

Refuse collection with separate newspaper collection

Loading time = 0.22 + 0.10 (items at stop)*
Coefficient of correlation = 0.98
Number of observations = 64

Refuse collection without separate newspaper collection

Loading time = 0.11 + 0.10 (items at stop)
Coefficient of correlation = 0.96
Number of observations = 239

* Not including newspaper bundles

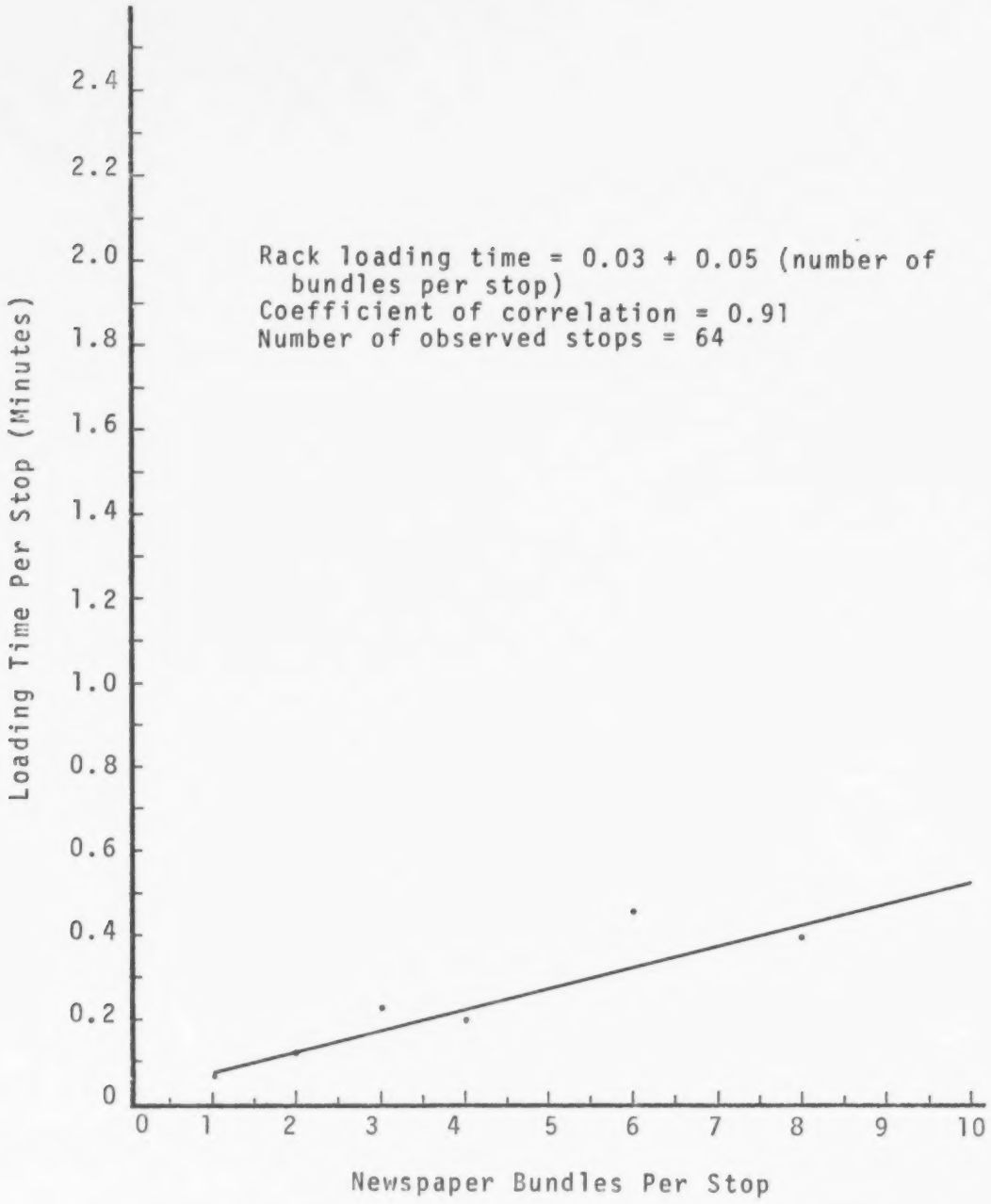

FIGURE B-3. Separated Newspaper Loading Time as a Function of Bundles per Stop -- Rack Approach

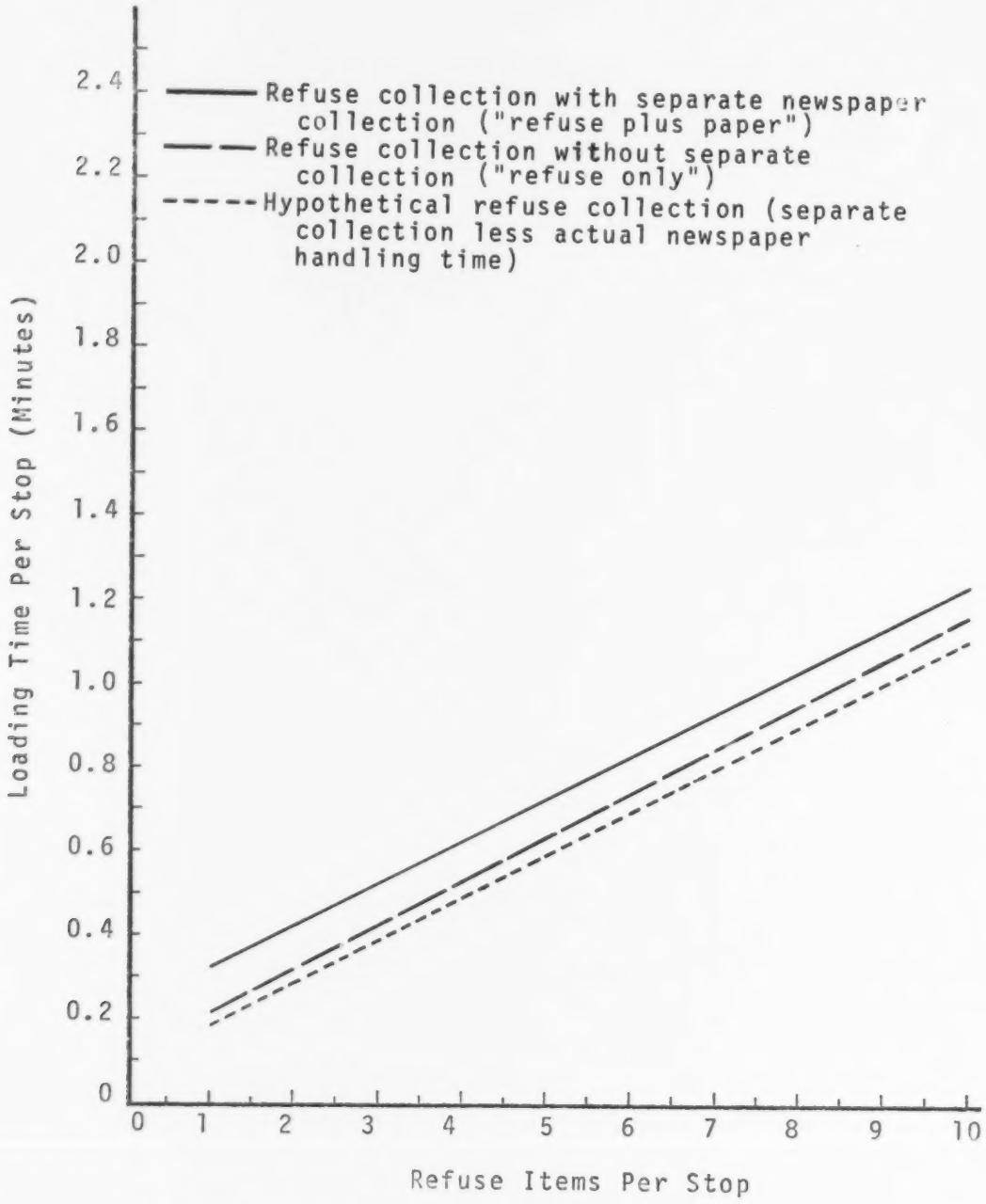

FIGURE B-4. Impact of Separate Collection on Refuse Collection -- Rack Approach

APPENDIX C

NEWPORT BEACH, CALIFORNIA

The City of Newport Beach is located 35 miles south of Los Angeles and has a population of about 57,000. Newport Beach initiated curbside collection of separated newspaper in September, 1974, with associated tonnages shown in Table C-1.

Newport Beach provides municipal collection service for residential refuse. Mixed refuse is collected twice weekly; separated paper is collected once per month using the separate truck approach.* Due to a wide variety of service area conditions, both rear- and side-loading refuse collection vehicles are used to provide mixed and separate collection service. For the purpose of gathering supportive data to this study, a Shu-Pak performing separate newspaper collection was monitored for one day. The results are shown in Figure C-1 in terms of newspaper loading time as a function of the number of bundles per stop.

To facilitate handling the newspaper, a transfer ramp was constructed in the city yard. The ramp configuration (Figure C-2) accommodates two 40 cu yd roll-offs. Construction cost for the concrete retaining walls, asphalt dumping surface and concrete apron was about $10,000.

---

* Implementation of the separate truck approach was accomplished by diverting three crews from refuse collection duties on newspaper collection days. After newspaper routes have been serviced, the three crews return to assist with refuse collection operations. In this manner, full utilization of equipment and labor is attained.

TABLE C-1

QUANTITIES OF NEWSPAPER
SEPARATELY COLLECTED
NEWPORT BEACH, CALIFORNIA

Month	Quantities of Newspaper Per Month (tons)	
	1974	1975
January	--	104
February	--	80
March	--	65
April	--	84
May	--	83
June	--	104
July	--	120
August	--	97
September	47	--
October	67	--
November	82	--
December	85	--

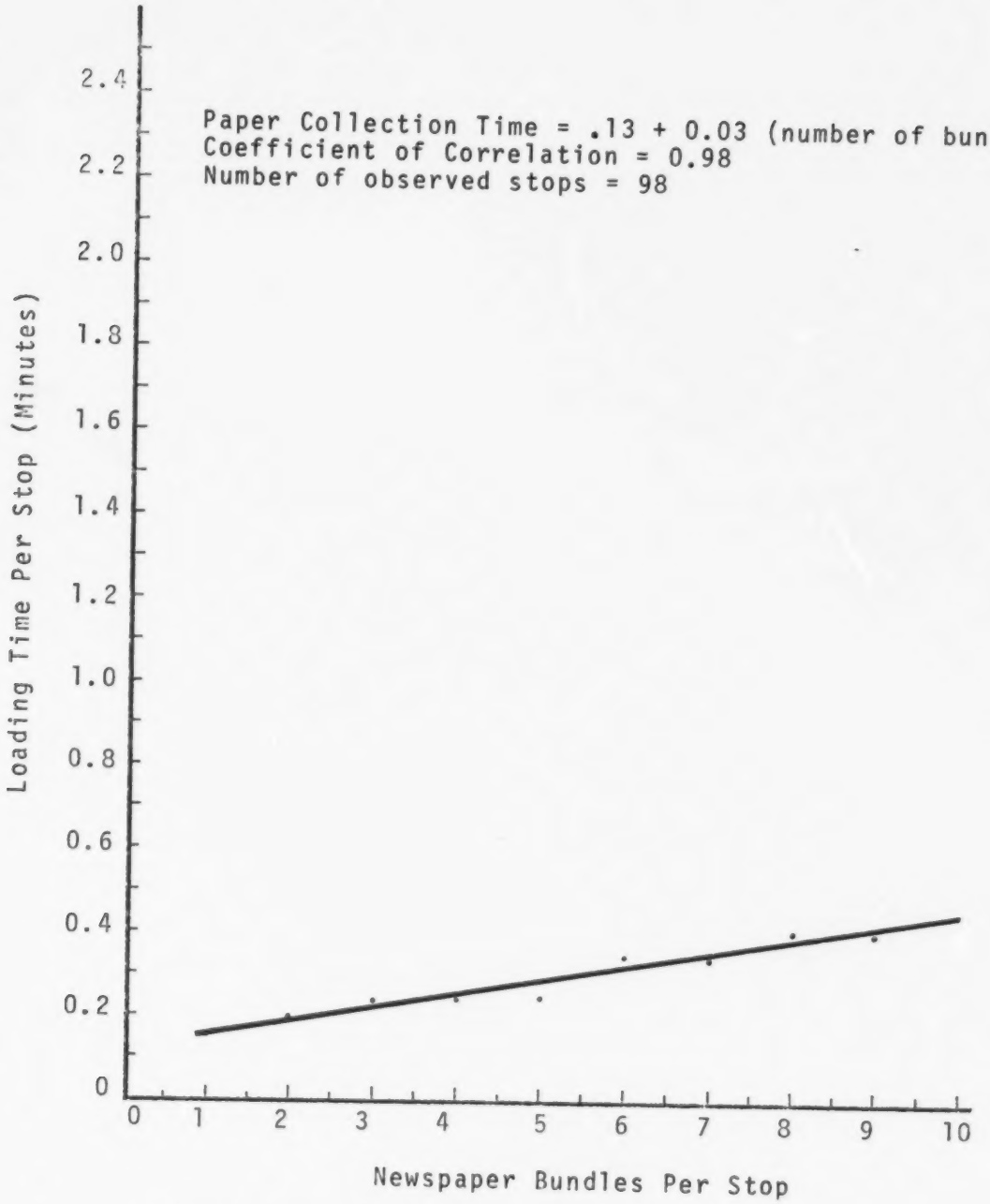

FIGURE C-1. Separated Newspaper Loading Time as a Function of Number of bundles -- separate truck approach

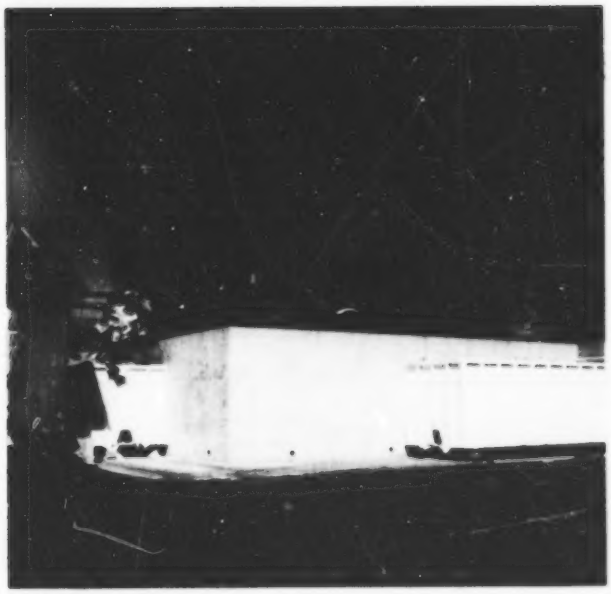

FIGURE C-2. Transfer Ramp Used for Separate Newspaper Collection, Newport Beach

APPENDIX D

SYSTEMS ANALYSIS DATA DEVELOPMENT

Data used to assess the impact of mixed and separate collection operations via compartmentalized, separate truck and rack approaches with respect to overall collection costs* are presented in this appendix. These data served as input to the collection model described in Appendix E. The model output estimates collection costs prior to implementing separate collection and the effective cost of collection after implementation.

Data Development

Data used to exercise the model are presented in Table D-1 and discussed in the ensuing text.

Collection Vehicle Capacity (V_c)

Collection vehicle type was constrained to a side-loading Shu Pak of 29 cu yd capacity although incorporation of a 3 cu yd compartment for separated materials reduced the effective capacity for mixed refuse to 26 cu yd for the compartmentalized alternative.

Collection Time per Stop (t)

The average time per stop for collection of mixed refuse and separated newspaper were based on the following:

Baseline (prior to separate collection) - collection time per stop and travel time between stops were derived from time studies conducted in Rancho Palos Verdes prior to and after initiation of the separate collection program (Appendix A).

Compartmentalization - collection time per stop and travel time between stops were derived from time studies conducted in Rancho Palos Verdes after implementation of the separate collection program via the compartmentalized approach.

---

*Overall collection cost considers the costs of both mixed and separate collection.

TABLE D-1

DATA FOR EXERCISING THE REFUSE COLLECTION MODEL

Variable	Baseline (Prior to Separate Collection)	Separate Collection Approach											
		Separate Truck											
		Compartmentalized/ Participation Rate			Mixed Refuse/ Participation Rate			Separate Collection/ Participation Rate			Rack/ Participation Rate		
		20	50	80	20	50	80	20	50	80	20	50	80
V_c (cu yd)	29	26			29			29			29		
t (min)													
Mixed*	1.18/1.00	1.19/ 1.03	1.20/ 1.05	1.21/ 1.08	1.17/ 0.99	1.16/ 0.96	1.14/ 0.94	--	--	--	1.20/ 1.02	1.22/ 1.04	1.24/ 1.07
Separate													
. 1/wk	--	--	--	--	--	--	--	.96	.72	.50	--	--	--
. 1/2 wk	--	--	--	--	--	--	--	1.00	.78	.56	--	--	--
. 1/mo	--	--	--	--	--	--	--	1.04	.82	.60	--	--	--
d (lbs/cu yd)	450	500			450			450			450		
Q (lbs)													
Mixed*	61/43	61/43			60/42	58/40	57/39	--			61/43		
Separate													
. 1/wk	--	--			--	--	--	13			--		
. 1/2 wk	--	--			--	--	--	26			--		
. 1/mo	--	--			--	--	--	56			--		

TABLE D-1 (Continued)

Variable	Baseline (Prior to Separate Collection)	Separate Collection Approach											
		Compartmentalized/ Participation Rate			Separate Truck						Rack/ Participation Rate		
					Mixed Refuse/ Participation Rate			Separate Collection/ Participation Rate					
		20	50	80	20	50	80	20	50	80	20	50	80
B (min)	13		13			13			13			13	
D (min)	15	18	20	20		15			15		20	24	29
K (min)	57		57			57			57			57	
C_v ($/min)	0.321		0.324			0.322			0.322			0.0322	
C_c ($/min)	0.096		0.096			0.096			0.096			0.096	
R ($/ton)	0		8,25			0			8,25			8,25	
S ($/ton)	0		2			0			2			2	

*Reflects time or weight estimates for first/second collection day per week.

Separate Truck - Collection time for separated newspaper via the separate truck approach was based on time studies conducted in Newport Beach (Appendix C) and the following assumptions:

Separate Collection Frequency	Newspaper Bundles per Participating Stop	Source of Estimate
1 wk	1.5	Rancho Palos Verdes
1/2 wk	2.7	Estimate
1 mo	3.9	Newport Beach

Figure D-1 was used to estimate travel time between stops at 20, 50, and 80 percent participation rates based on time studies in Rancho Palos Verdes where the average distance between stops is 93 ft in hilly terrain. The estimated travel time was added to the "Newport Beach loading time" and recorded in Table D-1.

From previous research, removal of newspaper from mixed residential refuse was calculated to reduce the number of containers set out for collection by about 0.25 per participating stop.* Using the Rancho Palos Verdes time study relationships presented in Appendix A, time for collecting mixed refuse in conjunction with the separate truck approach was calculated and 0.30 min added to account for travel time between stops.

Rack - Based on the results of the Fullerton time study (Appendix B), the time to load newspaper into a rack did not vary with fill rate, although an incremental loading time of 0.07 min for 1.5 bundles per participating collection stop was added.

In Rancho Palos Verdes, the rack would have the capacity to hold separated newspaper from 40 homes based on the following conditions:

---

* SCS Engineers, Separate Collection Studies, 1974.

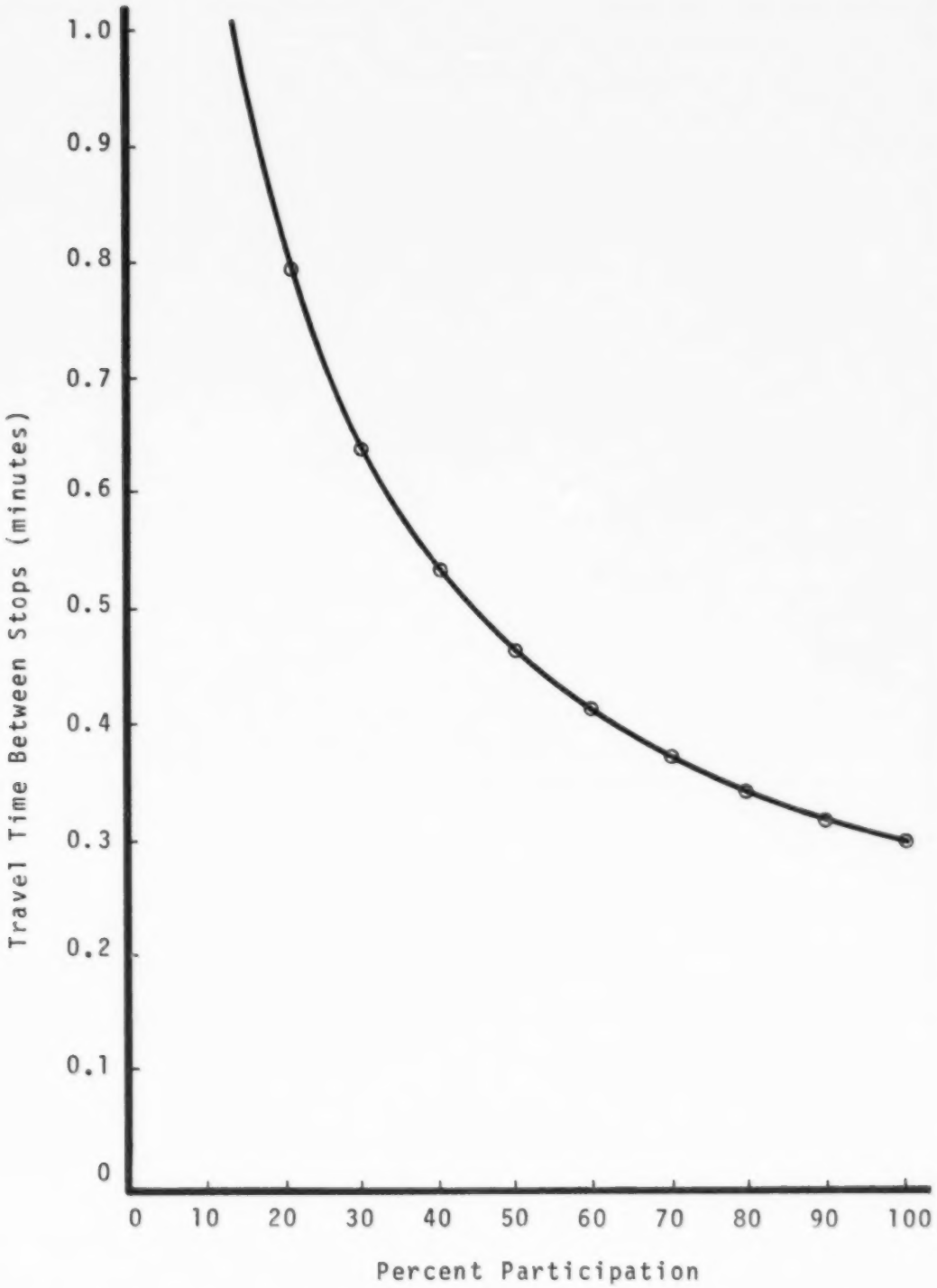

FIGURE D-1. Separate Collection Travel Time Between Stops as a Function of Participation Rate -- Rancho Palos Verdes

Condition	Source
• Newspaper has an in-place rack density of 360 lbs/cu yd	Fullerton
• 1.5 bundles per participant	Rancho Palos Verdes
• Each bundle weighs 9 lbs	Rancho Palos Verdes

As would be expected, removing recyclable portions of mixed refuse for separate collection increases the number of households that can be served per "mixed truck load." Table D-2 presents the number of households serviced per load via the rack approach for each of the assumed participation rates. Based on participation rate, the number of households placing newspaper out for separate collection is also tabulated. Observations in Rancho Palos Verdes indicate participants are equally inclined to set out newspaper on the first and second collection day of the week. For example, a 20 percent participation rate has been assumed to receive participation from 10 percent of the households on the first collection day of the week and a corresponding sum on the second collection day. Based on the preceding assumptions, the number of racks of newspaper filled per truckload is also shown in Table D-2 based on the factor of 40 participating stops per rack load.

Using the number of participating households from Table D-2 and the estimated incremental newspaper handling time per participating household, the average time per collection stop for rack operations was calculated at the various participation levels as follows:

$$t_i = \frac{1}{S_i} \left[(S_i - P_i)\ (t_m) + (P_i)\ (t_m + t_n) \right] + t_s$$

where:

t_i = average time per collection stop at participation rate i (min)

S_i = number of collection stops per load at participation rate i (households)

P_i = number of participating households at participation rate i (households)

TABLE D-2

RACK FILL RATE VERSUS PARTICIPATION
- 29 CU YD VEHICLE -

Participation Rate (%)	Households Per Load* $\frac{(Vc)(d)}{Q}$ (no.)	Households Participating (no.)		Newspaper Racks Filled Per Load Per Collection Day (no.)
		Total	Each Collection Day+	
0 (mixed refuse collection only)	214	0	0	0
20	217	43	22	0.6
50	225	112	56	1.4
80	229	183	92	2.3
100	231	231	115	2.9

*Based on first collection day of week.
+Assumes half of participants place out separated newspaper on each collection day per week.

t_m = average time per collection stop for mixed refuse (min)

t_n = average incremental time per collection stop for handling newspaper (min)

t_s = average travel time between stops on the route (min)

Exercising the preceding equation with participation percentages of 20, 50, and 80 yields the rack collection times (t) shown in Table D-1.

Collected Waste Density (d)

Based on refuse quantities collected during the Rancho Palos Verdes study, the compacted density of mixed refuse with or without newspaper was calculated to be 450 lbs/cu yd for each alternative except the compartmentalized approach to separate collection. With respect to the compartmentalized vehicle, the same loads were obtained with 3 cu yd less body volume. Thus, compacted density in the effective body capacity (26 cu yd) was calculated to be 500 lbs/cu yd.

Quantity of Refuse per Stop (Q)

The quantity of refuse per collection stop was calculated to be 104 lbs per household per week with 61 lbs set out on the first collection day of the week and 43 lbs on the second day. These data were derived from the periods during which the "before and after" time studies were conducted (October/November and June/July). As such, the quantities are representative of typically high generation periods which are also the most demanding of collection equipment and labor.

For the separate truck approach, removal of newspaper at various participation rates from the mixed waste has impact on both mixed and separate collection quantities. Participating households were estimated to generate about 13 lbs of newspaper per week (1.5 bundles/wk, 8.7 lbs/bundle). Again recognizing householder propensity to set out newspaper on either collection day, the quantity of mixed refuse per collection stop at the exemplary 20, 50, and 80 percent participation rates was apportioned accordingly.

Collection Route to Disposal Site (B)

Based on Rancho Palos Verdes time studies, the average one-way driving time between the collection route and the disposal site for vehicles hauling mixed refuse was 13 min.

Haul time for the separate truck collecting newspaper only was also assumed to be 13 min in that the bins for separated newspaper were located at the Palos Verdes Landfill.

Disposal (D)

The average time spent at the Palos Verdes landfill site to discharge mixed refuse was 15 min.

Additional time must be included in the disposal time for varying levels of participation associated with the rack and compartmentalized operations.

Rack. The number of times a rack would fill while collecting one full load of mixed refuse was shown in Table D-2. Based on the fill rate, the number of times the collection vehicle would be required to transfer newspaper into the route foreman's truck* is presented below:

Participation Rate (%)	Newspaper Racks Filled Per Load (no.)	Transfer Requirements Per Load (no.)
0	0	0
20	0.6	0
50	1.4	1
80	2.3	2
100	2.9	2

In addition, newspaper unloading at the disposal site was assumed to be required for rack operations. The "out-of-the-way" driving time from the working face of the Palos Verdes landfill to the transfer ramp required an additional 2 min of driving time. Added to this time is the time to manually unload the rack which was assumed to be the same as on-route transfer (5 min) and proportional to the amount of paper in the rack at the time a full load of mixed refuse was attained. The times shown in Table D-3 were estimated for disposal operations with the rack approach.

Compartmentalized. Based on tests performed prior to formal initiation of the separate collection program in Rancho Palos Verdes, the compartment was filled with bundled newspaper totaling 1,280 lbs. To attain this weight, however,

*Assumes a Fullerton transfer operation (Appendix B) whereby the collection vehicle does not leave the route.

TABLE D-3

ESTIMATED DISPOSAL TIME: RACK APPROACH

Participation Rate (%)	On-Route Transfer Requirements (no.)	Total Transfer Time (min)	Time to Empty Rack at Disposal Site (min)	Dumping Time for Mixed Refuse (min)	Total Disposal Time (min)
0	0	0	0	15	15
20	0	0	5	15	20
50	1	5	4	15	24
80	2	10	4	15	29
100	2	10	6	15	31

required the driver to climb on the loading bucket and manually rearrange the load through the bulkhead opening. This procedure is not acceptable from a safety standpoint. Compartment loads totaling about 1,100 lbs were attainable before manual rearrangement was required. This weight converts to an in-place density of about 370 lbs/cu yd which is about the same as that achieved in Fullerton via the rack approach (360 lbs/cu yd). Based on the methodology discussed earlier in this appendix to develop the rack fill rates, Table D-4 presents the compartment fill rates in terms of participation. Due to the concept configuration which requires refuse to be dumped prior to newspaper, the compartmentalized approach has the capacity to accommodate 82 homes per load. Thus, at the Rancho Palos Verdes newspaper generation rate (13 lbs per household per week) the compartment can cope with a 75 percent participation rate before practical capacity is attained. With no on-route transfer performed, the only incremental disposal time is at the disposal site which has an out-of-the-way penalty of 5 min for each dump. At a 20 percent participation rate, the truck would not be required to dump separately collected newspaper until the end of the day. Based on this assumed practice, and a generality of two loads of mixed refuse per day in Rancho Palos Verdes, the incremental disposal time is 2 to 3 min per load. At the higher exemplary participation rates the full 5 min of newspaper unloading time has been added to the normal disposal time of 15 min.

Non-Productive Time (K)

Non-productive time for such functions as dispatch, lunch and relief, yard to route time, and disposal site to yard time averaged 57 min during the time studies.

Equipment Cost (Cv)

An unmodified, 29 cu yd Shu-Pak has an initial cost of about $36,000. The average BFI fleet cost for this vehicle type equates to $19.25 per hour and includes depreciation, interest, operations, maintenance, and overhead (administration, facilities, and land). This cost converts to $0.321 per minute for the basic vehicle.

Compartmentalization has an installed cost of about $1,400 (compartment, bucket, cylinders, pumps, switches, etc.). Depreciated on a straight line basis over a 7-year period and a 50 hr work week, the $1,700 initial cost converts to $0.001 per minute of operation. During the course of the study no compartment maintenance was required. However,

TABLE D-4

COMPARTMENT FILL RATE VERSUS PARTICIPATION
- 29 CU YD VEHICLE* -

Participation Rate (%)	Households Per Load+ $\frac{(Vc)(d)}{Q}$ (no.)	Households Participating (no.)		Compartments Filled Per Load Per Collection Day (no.)
		Total	Each Collection Day#	
0 (mixed refuse collection only)	214	0	0	0
20	217	43	22	0.3
50	225	112	56	0.7
80	229	183	92	1.1**
100	231	231	115	1.4**

*26 cu yd mixed refuse capacity plus 3 cu yd compartment.
+Based on first collection day of week.
#Assumes half of participants place out separated newspaper on each collection day per week.
**Compartmentalized approach cannot accommodate fill rate greater than 1.0.

hydraulic cylinders require repacking once or twice per year and some hydraulic hose maintenance/replacement will be necessary over the equipment life. Thus, the allocated compartment cost was doubled to $0.002 per min to estimate life costs.

The rack cost of $500 was similarly treated, and an incremental $0.001 per min was added to the basic Shu-Pak cost.

A paper transfer ramp was assumed to be required for both the separate truck and compartmentalized approaches. The $10,000 spent by Newport Beach to construct a concrete reinforced ramp was assumed to be a representative cost. Depreciating this cost on a straight line basis over a twenty-year period, converts to a cost of about $0.003 per min. Allocation of this cost would be variable with respect to the number of trucks using the ramp. As a proxy for this evaluation, $0.001 was included in the equipment costs for separate truck and compartmentalized alternatives.

Collection Labor Cost (Cc)

Shu-Pak drivers currently earn $4.10 per hour and are guaranteed a 50 hr work week. Fringe benefits equivalent to $0.80 per hour and overhead equivalent to $0.85 per hour result in a burdened labor cost of $5.75 per hour or $0.096 per min.

Newspaper Revenue (R)

At the time of the evaluation, used newspaper was selling at $8 per ton, at best. A revenue rate of $25 per ton was also evaluated to determine the impact of revenue on the feasibility of alternative separate collection approaches.

Disposal Savings (S)

BFI operations in Rancho Palos Verdes use the Palos Verdes Landfill site owned and operated by the Los Angeles County Sanitation Districts for which a $2 per ton disposal fee is paid. Each ton of newspaper separately collected was credited with diverted disposal savings amounting to this cost.

APPENDIX E

COLLECTION MODEL

The many approaches to performing refuse collection and/or separate collection of recyclable materials can be described with a mathematical model. The model defines the mathematical relationships between collection time, tonnage collected, haul time, equipment capacity, costs, and other factors. Through repeated calculations, the model may be used to analyze alternative collection approaches to minimize and/or compare applicable costs.

The following factors affecting the efficiency of mixed or separate refuse collection were included as variables in the model:

1. Average quantity of mixed or recyclable material generated per residential unit.

2. Average collection time for each residential unit, including travel time to the next stop.

3. Average driving time between the route and the disposal site.

4. Total non-productive time: travel time between yard (vehicle storage area) and route and between the disposal site and the yard; breaks, relief; and dispatch.

5. Average disposition time per load at the disposal site for mixed and/or separated newspaper.

6. Crew size.

7. Equipment type, capacity, and performance characteristics.

The following assumptions were used during the calculations:

1. The minimum partial load allowed was one-fourth of the vehicle load capacity (i.e., a collection vehicle was not allowed to return to the collection route after emptying a full load unless sufficient time remained to collect at least a quarter of a load).

2. The maximum work day was constrained to 500* minutes.

3. Crew members were paid for 500 minutes; if time was not sufficient to collect a partial load, they were dismissed early, but paid for a full day.

Physical and cost variables used in the model were defined as follows:

Physical Variables

X_n: Total time to collect and offload n loads (crew-min/day).

V_c: Vehicle capacity (cu yd).

t: Average collection time per stop plus travel time to the next stop (min).

d: Average density of material in the vehicle (lbs/cu yd).

Q: Average quantity of material per stop (lbs).

B: Average one-way driving time between route and disposal site (min).

D: Average disposal time (min).

K: Total non-productive time per day - includes dispatch, breaks, yard to route time, and disposal site to yard time (min).

Cost Variables

C_c: Cost of collection labor ($/crew-min).

C_v: Cost of collection vehicle ($/truck-min).

R: Revenue from materials separately collected ($/ton).

S: Disposal savings from materials separately collected ($/ton).

Alternative collection frequencies for the separate truck alternative may be evaluated by changing the value of the average quantity of material collected per stop (Q) in

*BFI crew members work six days per week with a 50-hour guarantee.

proportion to the monthly generation rate. For example, evaluation of a separate truck collection program where once per month collection is to be performed and the average newspaper generation rate is 56 lbs/mo would have a Q value of 56. If weekly newspaper collection is to be evaluated, a Q value of about 13 lbs would be used (56 ÷ 4.3 weeks/mo).

Various participation rates may be evaluated by changing the value of the average collection time per stop (t). As previously defined, the value of t is comprised of the time to collect materials per stop (i.e., dismount truck, load, remount truck) plus the driving time to the next stop. The collection portion of t was assumed to be constant at a specific collection frequency due to the average quantity of material collected per stop being held constant.

The second variable in the time calculation, travel time to the next stop, is a function of participation rate. An even distribution of participants and material generation along a 10-home segment of a route was assumed. For example, an overall participation rate of 10 percent for one side of the street collection assumes that one out of each ten homes along the route sets out newspaper. Thus, travel time was calculated based on collecting materials at the first home on the route and driving past the subsequent nine homes to the next participant. Similarly, a 50 percent participation rate was evaluated by assuming a collection stop is made at every other home along the route.

Calculations

Using the variables discussed above, a series of seven calculations are necessary to evaluate the performance and cost characteristics of alternative collection operations:

1. Calculate the time to collect the first and successive loads (whole and partial).
2. Convert collection time into collection cost.
3. Determine tonnage collected.
4. Determine number of residences served.
5. Convert tonnage collected into dollar savings (revenue plus diverted disposal savings).
6. Compute net cost of separate collection (collection cost less savings).

7. Convert net cost into meaningful factors (cost/ton, cost/residence).

Step 1: Collection Time Calculation

The total time in minutes to complete one load (collect and offload) can be calculated as follows:

$$X_1 = \frac{V_c t d}{Q} + B + D + K$$

At the disposal site, a decision is made:

If $X_1 + 2B + D = 500$, only one full load was collected for the day;

If $X_1 > 500$, only a single partial load was collected for the day, and the following calculation made:

$$500 = (a)\frac{V_c t d}{Q} + B + K + D$$

Solving for the value of (a) gives the fraction of the truck capacity used for the partial load;

If $X_1 + 2B + D < 500$, the truck was sent for a second or more loads as time permitted.

In general, the truck made a total of n trips, where:

$$X_n: = (n + a - 1)\frac{V_c t d}{Q} + (2n - 1) B + K + nD$$

provided $X_n \leq 500 \leq X_n + 1$, and $a \geq 1/4$;

if $a \leq 1/4$, only $(n - 1)$ trips are made.

The results provided collection time in terms of crew-minutes per day and the quantity of material collected by the vehicle. In this case, crew members were paid for a 500 min day even if finished early. (If collection time were not constrained and overtime permitted, appropriate modifications would be required to the preceding equations.)

Step 2: Collection Cost Calculation

Under the conditions imposed, crew members were paid for a full day's work even if finished early. Labor costs were

converted to a cost per crew per min ($/min) based on current hourly rates of the driver including overhead and fringe benefits to express the daily collection time, X_n, in labor costs. Similarly, vehicle costs (amortization, overhead, fuel, oil, and maintenance) were converted to a cost per vehicle per minute ($/min) to apportion vehicle costs. Generally, daily collection time was converted to cost as follows:

$$\text{Daily Collection Cost} = X_n (C_c + C_v)$$

When an undertime situation occurred, the collection cost relationship was as follows:

$$\text{Daily Collection Cost} = 500\ C_c + [480 - (480-Xn)]\ Cv$$

This relationship represents a proxy for vehicle undertime.

Step 3: Tonnage Collected Calculation

Revenue was based on newspaper tonnage collected. The volume of material collected per day was converted to tonnage by the following relationship:

$$\text{Tonnage Collected} = \frac{\sum Vd}{2{,}000}$$

Volume (V) may be calculated by multiplying the truck capacity (V_c) by the number of full and partial loads collected in Step 1. Average density (d) was derived from subtracting the vehicle tare weight from loaded vehicle weight and dividing by V_c.

Step 4: Residences Served Calculation

The number of residences served per day by each crew depends on many factors: participation rate, truck volume, crew size, etc. The factors required to estimate residential service rate, however, will have been developed during Step 1. Thus, the service factor may be estimated by dividing the multiplicative sum of the volume collected and density by the average quantity of materials per stop:

$$\text{Services} = \frac{\sum Vd}{Q}$$

Step 5: Dollar Savings Calculation

Revenue (R) from recyclable materials and diverted disposal savings serve to reduce overall collection costs. Revenue

was calculated by multiplying tonnage collected (Step 3) by the rate paid by the paper stock dealer.

Diverted disposal savings (S) were calculated based on local disposal conditions at the rate of $2 per ton.

Step 6: Net Collection Cost Calculation

The net cost of separate collection operations was calculated by subtracting the results of Step 5 from the results of Step 2:

$$\begin{bmatrix}\text{Total separate}\\ \text{collection cost}\end{bmatrix} - \begin{bmatrix}\text{Revenue plus}\\ \text{diverted}\\ \text{disposal cost}\end{bmatrix} = \begin{bmatrix}\text{Net separate}\\ \text{collection}\\ \text{cost}\end{bmatrix}$$

or

(Step 2) - (Step 5) = Step 6

Step 7: Performance Factors Calculation

Based on the net cost calculation (Step 6), performance measures such as cost/ton and cost/residence can be calculated. Net cost per ton was calculated by simply dividing cost by the tonnage collected:

$$\frac{\text{Net Cost per Day}}{\text{Tonnage Collected per Day}} \quad \text{or} \quad \frac{\text{Step 6}}{\text{Step 3}}$$

The cost per residence per month was calculated by dividing the daily cost by the number of residences serviced per day (Step 4) and multiplying this sum by the collection frequency (in terms of collections per residence per month):

$$\begin{bmatrix}\text{Cost per}\\ \text{Residence}\end{bmatrix} = \begin{bmatrix}\frac{\text{Net Cost per Day}}{\text{Number of Residences}}\\ \text{Served per Day}\end{bmatrix} \times \begin{bmatrix}\text{Collections per}\\ \text{Residence per}\\ \text{Month}\end{bmatrix}$$

or

$$\frac{\text{Step 6}}{\text{Step 4}} \times \begin{bmatrix}\text{Collection Frequency}\\ \text{Factor}\end{bmatrix}$$

where

Frequency of Collection	Factor
Once per month	1
Once per 2 weeks	2.16
Once per week	4.33

µo1413